DEPARTMENT OF THE ARMY
TULSA DISTRICT, CORPS OF ENGINEERS
1645 SOUTH 101ST EAST AVENUE
TULSA, OK 74128-4609

# WICHITA RIVER BASIN PROJECT REEVALUATION
## RED RIVER CHLORIDE CONTROL PROJECT

U.S. Army Corps of Engineers
Tulsa District

DRAFT
June 2002

# FORMULATION APPENDIX

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**GUIDANCE**



**LOW FLOW, CONCENTRATION DURATION, AND LAKE KEMP ANALYSIS**

# GUIDANCE

DEPARTMENT OF THE ARMY
TULSA DISTRICT, CORPS OF ENGINEERS
P. O. BOX 61
TULSA, OKLAHOMA 74121-0061

REPLY TO
ATTENTION OF:

CESWT-PL

MEMORANDUM FOR Commander, Southwestern Division,
ATTN: CESWD-ETP, 1114 Commerce Street,
Dallas, TX 75242-0216

SUBJECT: Supplemental Assessment Report (SAR) to the Supplement to the Final Environmental Statement, Red River Chloride Control Project (RRCCP), Texas and Oklahoma

1. References:

a. Memorandum, OASA(CW), 20 September 1996, subject: Red River Chloride Control Project, Texas and Oklahoma.

b. Memorandum, CECW-BC/CECW-PC, 6 November 1996, subject: Red River Chloride Control Project in Texas and Oklahoma.

c. 1st Endorsement, CECW-BC/CECW-PC, CESWD-ETP-S/CESWD-PMC, 20 November 1996, subject: Red River Chloride Control Project in Texas and Oklahoma.

2. The above references requested that the Tulsa District prepare a Supplemental Assessment Report (SAR) to the Supplement to the Final Environmental Statement (SFES). The enclosed SAR identifies and explores, in a preliminary fashion, the feasibility of desalinization, mixing, and partnership options, either alone or in combination, that might constitute a workable, more environmentally sensitive solution to long-term water needs in the Red River Basin. The SAR outlines these options and discusses the preliminary costs, environmental impacts, and their potential implementability.

3. The SAR indicates that various methods of desalinization and blending at the point of use are more costly than the authorized project. The environmental impacts of these methods have not been analyzed to the same level of detail as the authorized project. Although these alternatives initially appear to have environmental advantages, there are numerous unknowns that could have significant adverse environmental impacts.

4. The SAR also identifies significant geographic shifts in water demands and discrepancies between governmental organizations in the forecasting of future water needs within the Red River Basin. It appears that while there is a decreased demand in the primary population center, the Dallas-Fort Worth area, there is a shortage of quality water to meet the demands in the

upper Red River area. Additional options were explored and are discussed in the report which might better satisfy the changing water demands.

5. I recommend the following actions be taken based on the findings of the SAR:

a. Prepare a Post Authorization Change (PAC) report for reformulation of the Red River Chloride Control Project (RRCCP). The PAC should include a basin-wide analysis of the water resource problems in the Red River Basin. Under the leadership of the Army Corps of Engineers, a multi-state, coordinated effort to evaluate demand for Red River water, with a broad view of the multiple resources of the region, would produce a comprehensive water development plan comprising cost effective, environmentally sensitive, and politically acceptable solutions to the water resources problems. This would be an exceptionally effective way for the Federal Government to help solve regional problems by establishing partnerships to share in the development, implementation, and funding of long-term water needs solutions. The study should be compatible with the initiatives of the State of Texas to meet water management policies as outlined in State Senate Bill 1 of the current Texas Legislature, as discussed in the SAR. No additional authorization is required; the study could be initiated at the direction of the Chief of Engineers and would be completed in approximately 18 months using currently available Construction General funds.

b. Complete construction of the Wichita River Basin portion of the RRCCP as outlined in Alternative 3 of Appendix G. This will help meet existing and future water quality requirements in the upper Red River Basin, and additionally, will recover benefits from the $61.2 million Federal investment in this portion of the project. Construction of this small portion of the RRCCP significantly reduces environmental impacts to the Red River Basin as previously identified for the entire authorized project. This would eliminate appreciable impacts to the aquatic ecosystem of the mainstem of the Red River, most major tributaries, and Lake Texoma. The need for additional brine storage reservoirs and associated selenium impacts would be eliminated. This will require minor modification of the SFES to reflect construction of only the Wichita River Basin portion of the RRCCP.

c. Release the SFES to the public, with the SAR included as an appendix. I would release the SFES with a Draft Record of Decision outlining our intent to complete only the Wichita River Basin portion of the project. This would allow interested parties to fully assess the impacts of the Wichita River Basin portion of the project, provide information which will further address desalinization, blending and partnership options, and complete the NEPA process. This also fulfills the requests of the States of Texas and Louisiana for release of the SFES.

6. Although the U.S. Army Corps of Engineers currently has no direct water supply or water quality planning mission, many Corps projects and activities play a major role in the water supply and water quality management concerns of others. Because of its regional perspective and its reputation as a trusted "honest broker," the Corps is uniquely positioned to coordinate and facilitate multi-purpose water resources planning by state and local entities. Building on the concepts in paragraph 5.a. above, the Army Corps of Engineers should actively initiate Federal leadership of a cooperative effort with the States of Texas, Oklahoma, Arkansas, and Louisiana to addresss multi-purpose water resource issues in this region. Water is a significant issue in all of the regional states, and no broad regional solutions are currently being addressed. States in the Red River Basin are addressing their individual water issues. The best and most aggressive example is Texas. There are no multi-state efforts, however, to study shared problems and investigate potential regional solutions. Corps of Engineers leadership is needed and warranted to develop a multi-state, coordinated effort to find economical, environmentally sensitive answers to water challenges. This would be an exceptionally effective way for the Federal Government to help solve regional problems by establishing partnerships to share in the development, implementation, and funding of long-term water needs solutions.

Timothy L. Sanford

Encl

TIMOTHY L. SANFORD
Colonel, EN
Commanding

CESWD-ETP-S (CESWT-PL/11 Feb 97) (1105-2-100) 1st End
Mr. Shaw//214-767-2312
SUBJECT: Supplemental Assessment Report (SAR) to the Supplement to the Final Environmental Impact Statement, Red River Chloride Control Project (RRCCP), Texas and Oklahoma

Commander, U.S. Army Engineer Division, Southwestern, ATTN: CESWD-ETP-S, 1114 Commerce Street, Dallas, Texas 75242-0216 12 FEB 1997

FOR Commander, U.S. Army Corps of Engineers, 20 Massachusetts Ave. NW, Washington, DC 20314-1000

1. I fully endorse the findings and recommendations of the subject report. My Planning and Program Management staffs and I have been full partners in this effort throughout its development.

2. The District Commander is ready to brief Mr. Lancaster personally in Washington, DC on this report and our recommendations. Because of the complexity and sensitivity of the findings and recommendations of this analysis, I highly recommend this course of action. The District Commander is also prepared to brief Mr. Lancaster at the Lake Truscott Project site in the Red River Basin, to give him a fuller understanding of the project as he makes his decision.

3. If you have any questions, please contact Mr. Peter Shaw, CESWD-ETP-S, at (214) 767-2312.

Encl
wd

Henry S. Miller Jr.
HENRY S. MILLER, JR.
Brigadier General, USA
Commanding

CF (wo/encl):
CESWT-PL

The following two-page, 13 November 1997 letter from John H. Zirschky is inserted into the eight-page correspondence chain for chronological continuity.

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
CIVIL WORKS
108 ARMY PENTAGON
WASHINGTON DC 20310-0108

13 NOV 1997

REPLY TO
ATTENTION OF

MEMORANDUM FOR DIRECTOR OF CIVIL WORKS

SUBJECT: Red River Chloride Control Project, Texas and Oklahoma - Evaluation of Wichita River Basin (October 1997)

We have completed our evaluation of the subject report, prepared by the Army Corps of Engineers Tulsa District, and the results of the policy compliance review summarized in CECW-AR memorandum dated October 27, 1997. In addition, my staff discussed the report and reviewed concerns with your staff via telephone conference call on October 30.

I have decided that I will support the effort to conduct a thorough reevaluation of the Wichita River Basin features. Three out of four scenarios presented in the report have positive benefit to cost ratios, with one estimate as high as 1.81 to 1. The report indicates that there is significant new information about regional changes in water demand and project benefits that should be considered when deciding whether to finish the Wichita River Basin features. Most of the features in the Wichita River Basin area already have been constructed, and completion of the remaining features (pipelines and collection facility) project will enhance the performance of the Wichita River Basin features.

The reevaluation study should not simply update prior analyses, but rather should include a thorough evaluation of all key assumptions and parameters that potentially effect water use and beneficial effects. The NEPA document accompanying the reevaluation report must be updated to include new information on environmental resources, impacts, and the effects of project features that have been in operation for the past few years. The NEPA document must include current views of environmental resource agencies and other interested parties. The reevaluation effort will have to be undertaken subject to the availability of funds. Finally, I urge you to identify a non-Federal partner to assume the O&M of the Wichita River Basin features.

Finally, I do not support an overall reevaluation of the remainder of the project due to uncertainties about environmental effects, the high economic costs involved, and because no non-Federal sponsor has been identified to cost share the study effort. If a cost sharing partner is identified the Corps is

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certainly free to propose this effort as a new study start for consideration under whatever policy and budgetary criteria are in force at the time. Thank you for your quick action on this matter.

Sincerely,

John H. Zirschky
Acting Assistant Secretary of the Army
(Civil Works)

12 DEC 1997

CECW-PC (CESWT-PL/11 Feb 97) 2nd End Fitzsimmons/clf/202-761-1974

SUBJECT: Supplemental Assessment Report (SAR) to the Supplement to the Final Environmental Impact Statement, Red River Chloride Control Project (RRCCP), Oklahoma and Texas

HQ U.S. Army Corps of Engineers, Directorate of Civil Works

FOR Commander, Southwestern Division

1. References:

a. Acting Assistant Secretary of the Army (Civil Works), 13 November 1997, memorandum for Director of Civil Works, subject: Red River Chloride Control Project, Texas and Oklahoma - Evaluation of Wichita River Basin (October 1997).

b. CECW-AR, 28 October 1997, memorandum for CECW-P, subject: Red River Chloride Control Project, Texas and Oklahoma - Evaluation of Wichita River Basin Completion.

c. CECW-AR, 19 March 1997, memorandum for CECW-PC, subject: Red River Chloride Control Project, Texas and Oklahoma - Unreleased Final Supplemental Environmental Impact Statement and Supplemental Assessment Report - Policy Compliance Review.

d. CECW-AR, 24 January 1997, memorandum for CECW-PC, subject: Red River Chloride Control Project, Texas and Oklahoma - Unreleased Final Supplemental Environmental Impact Statement - Preliminary Policy Compliance Review.

2. Based on the reference 1.a guidance (enclosed) and the various policy compliance reviews (references 1.c, 1.d, and 1.e), further development of the Red River Chloride Control Project (RRCCP) may proceed within the constraints below.

3. A reevaluation of the Wichita River basin features of the authorized RRCCP may be initiated subject to the availability of funds and the application of the following guidance:

a. This effort will be formally referred to as the "Wichita River Basin Project Reevaluation."

b. No cost-sharing is required for the reevaluation. A non-Federal entity may have to agree to assume operation and maintenance responsibilities for the completed and recommended project features before further construction will be included in future budgets.

c. The reevaluation report should be accompanied by either a new National Environmental Policy Act (NEPA) compliance document or a substantially revised version of the Final Supplemental Environmental Impact Statement. The NEPA compliance document should focus on the Wichita River basin features, including new information on environmental resources, impacts, and the effects of the completed features. Current views of the environmental resource agencies, other interested parties, and the public should be included.

d. The reevaluation and the NEPA document should address the referenced policy compliance review comments, as they may apply. Key economic analysis assumptions and parameters should be thoroughly evaluated and documented, particularly:

(1) Your reevaluation must recognize that there is no single correct water use projection. The reevaluation would be most meaningful if decision makers were provided information about the likelihood of a range of outcomes. This could be accomplished through a presentation and use of the water use projections in a risk format.

(2) An estimate of the likely response to water quality improvements, which is reflective of farmers' current risk management practices, is critical to deriving a reasonable estimate of agricultural benefits.

(3) The relationship between salinity and damages used in the economic analyses should reflect more current information and actual experience. In addition, the assumption of a linear relationship between salinity and damages must be revisited. For example, a simple verification or rejection of this assumption may be possible through research on replacement rates of a single item (e.g., water heaters) for communities with high, low and average salinity rates.

(4) The timing of project implementation should maximize net benefits. This is a concern because much of the municipal and industrial water demand does not occur until the year 2010 and later.

(5) The operation, maintenance, repair, replacement, and rehabilitation (OMRR&R) costs should be presented in greater detail, including the fixed and variable costs.

e. A study plan should be submitted to CECW-PC for review to help ensure common expectations at all levels for the reevaluation scope and methods. The study plan should explicitly identify the alternatives to be examined. An issue resolution conference (IRC) may then be scheduled, if needed, to address unresolved questions about conducting the reevaluation.

f. The draft report and NEPA compliance document should be forwarded to CECW-AR and CECW-PC for review and approval following an independent technical review and legal review certification, and prior to public review. An IRC similar to a feasibility review conference may be necessary.

4. A budget request may be submitted to initiate a new-start General Reevaluation Report to review unmet water resource needs and problems in the Red River basin outside the Wichita River basin, after a non-Federal entity provides a letter indicating an intent to cost share the new study.

5. A budget request may be submitted to initiate a broader cooperative study of multipurpose water resource issues and regional solutions in a two-phase, General Investigation study. The budget request should identify a cost-sharing sponsor and clearly distinguish the purpose of this new start from the above reevaluations.

FOR THE COMMANDER:

Encl

RUSSELL L. FUHRMAN
Major General, USA
Director of Civil Works

CESWD-ETP-S (CESWT-PL/11 Feb 97) (1105-2-100) 3rd End
Mr. Shaw//214-767-2312
SUBJECT: Supplemental Assessment Report (SAR) to the Supplement to the Final Environmental Impact Statement, Red River Chloride Control Project (RRCCP), Oklahoma and Texas

Commander, U.S. Army Engineer Division, Southwestern, ATTN: CESWD-ETP-S, 1114 Commerce Street, Dallas, Texas 75242-0216

FOR Commander, Tulsa District, ATTN: CESWT-PL

1. The CECW-PC 2nd Endorsement provides guidance for further actions related to the Red River Chloride Control Project (RRCCP). In addition, discussions with Headquarters personnel have provided further information and context for the following items in the 2nd Endorsement.

a. Paragraph d.(1) indicates that water use projections could be presented in a risk format, to provide decision makers with information about the likelihood of a range of outcomes. This does not necessarily imply formal risk and uncertainty modeling (*e.g.*, Monte Carlo simulation), but rather the display of a range of water use projections, with a subjective assessment (including reasons, discussion, analysis) of why each of the numbers is more or less likely.

b. Paragraph d.(2) notes the importance of estimating the likely response of agricultural water users to water quality improvements, based on farmers' current risk management practices. The emphasis is on explicit analysis based on real-world information rather than simple extrapolation of abstract models. Farmers generally have some risk management strategy based on, among other things, their assessment of weather uncertainties over the growing season (such as temperature and moisture) mitigated by the availability and quality of irrigation water, and the resulting impact on crop production (by kind of crop and maturity days for different varieties of the same crop). These ultimately affect irrigation water use projections, and would potentially be affected by the presence of the Wichita River Basin Project. Much of this information may be readily available from county extension agents in the region or a university school of agriculture.

2. In addition to the above, you should generally review the previous exchanges of coordination on this project between the CESWT-PL, CESWD-ETP, and CECW-PC/AR staffs. If you have any questions, please contact Mr. Peter Shaw, CESWD-ETP-S, at (214) 767-2312.

/s/

Encls
nc

DONALD R. HOLZWARTH
Colonel, EN

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
WASHINGTON, D.C. 20314-1000

REPLY TO
ATTENTION OF:

CECW-PM

24 MAY 2001

MEMORANDUM FOR Commander, Southwestern Division (CESWD-CMP)

SUBJECT: Wichita Basin, Texas, Alternative Formulation Briefing - Project Guidance Memorandum

1. An Alternative Formulation Briefing (AFB) read ahead package was submitted to HQUSACE on 16 Jan 2001. Initial comments were provided to the District via email on 5 Feb 2001, and responses to comments were submitted by the District on 22 Feb 2001. Additional comments were sent by HQUSACE via email on 16 April 2001, and responses were submitted by the District on 18 April 2001. The AFB was held telephonically on 19 April 2001. A list of attendees is provided as enclosure 1. A project field trip was not necessary as one was provided for an In-progress Review in April 2000.

2. The AFB documentation (enclosure 2) provides an identification of each issue, a district response, a summary of discussion of the issues at the AFB, and a statement of resolution and or required actions. Upon completing the required actions as outlined in enclosure 2 and concurrence by SWD, the district may submit the draft report to the Environmental Protection Agency and circulate it for public review.

FOR THE COMMANDER:

James F. Johnson

2 Encls

JAMES F. JOHNSON
Chief, Planning and Policy Division
Directorate of Civil Works

Wichita AFB Attendees List:
19 APR 2001

Tulsa District
1. Marc Masnor, CESWT-PE-P (via telephone)
2. Jim Sullivan, CESWT-PE-P
3. Sue Haslett, CESWT-PE-P
4. Jim Randolph, CESWT-PE-E
5. David Combs, CESWT-PE-E
6. Dallas Tomlinson, CESWT-EC-H
7. Richard Bilinski, CESWT-PP-C

Southwestern Division
1. Peter Shaw, CESWD-CMP
2. Jo Ann Duman, CESWD-CMP
3. Tommy Knox, CESWD-CMC

Headquarters, USACE
1. Paul Blakey, CECW-PM
2. Steve Cone, CECW-PC
3. John Downey, CERE-C-WR

Enclosure 1

CECW-PM
Blakey

19 May 2001

# Wichita Basin, TX
# Alternative Formulation Briefing

**Introduction**. The Tulsa District was directed to reevaluate the Wichita River Basin features of the authorized Red River Chloride Control Project. The purpose of the reevaluation is to reexamine the economic feasibility of chloride control alternatives and the environmental impacts of those alternatives. The General Reevaluation Report (GRR) was initiated in 1997 and is scheduled for completion in September 2001. The Alternative Formulation Briefing (AFB) for the study was held on 19 April 2001, via telephone conference call. District participants were Marc Masnor, Lead Planner; Rich Bilinski, PM; Jim Sullivan, Economist; Jim Randolph, Biologist; Dallas Tomlinson, Hydrologist; David Combs, Chief, Environmental Resources Branch; Sue Haslett, Chief, Planning Branch. Southwestern Division participants were Peter Shaw and Jo Ann Duman of Planning, and Tommy Knox of Programs. HQUSACE participants were Paul Blakey and Steve Cone of Planning and Policy, and John Downey of Real Estate.

**Authorizing Laws**. The project was authorized for construction in 1966 and is partially constructed. Other significant authorizations include the Flood Control Act of 1970; Section 74, Water Resources Development Act of 1974; Section 153, Water Resources Development Act of 1976; and Section 1107, Water Resources Development of 1986.

**Project Purpose and Scope**. The Wichita River Basin Project consists of chloride control features in the Wichita River Basin, a tributary of the Red River, in Texas. The study area includes north central and northeastern Texas, including the Dallas and Fort Worth region and the region along the Red River as far downstream as Shreveport, Louisiana. The goal of the project is to reduce the naturally occurring chloride and total dissolved solid concentrations in the Red River and Wichita River basins to allow the economical use of water for municipal, industrial, and agricultural purposes.

**AFB Comments/Responses/Discussion/Required Actions.** Final HQUSACE comments, District responses to comments, results of the AFB discussion, and required actions for each comment are provided, below.

**1. <u>M&I Analyses</u>.**

**Comment:** Draft report needs to more fully lay out and explain the M&I water use projections over time, the cost of alternative sources, and the derivation of benefits. Currently, the AFB materials rely on prior reports and analysis methodologies and therefore are not fully explained in the materials submitted to HQ. It is important that not only HQ/OASA(CW) reviewers and decision makers understand the analytical assumptions and methodologies, but that the public and potential stakeholders understand.



Enclosure 2

**Response**: Concur. The draft report will fully lay out and explain the M&I water demands, supplies, and net needs, as presented in the State Water Plan. The four volume Region C plan presents several demand scenarios over time with a most likely selected for comparison to existing and future water supplies. Region B presents a consensus water demand as well as existing and potential supplies. Both regions have developed a water management strategy in some detail. The draft report will discuss out the analytical assumptions and methodologies used to develop this data. The Huitt-Zollars report has developed the costs of alternative sources as well as the cost/damage for utilization of the Wichita/Red River. The derivation of benefits is similar to past studies and will be explained in detail; however, the least cost alternative on a unit (1000 gal or mgd) basis may not be the best or least cost alternative, since the total capital cost of an alternative may be quite high and unaffordable by an water user entity. The AFB materials' purpose was to lay out the direction and source of data for the evaluation. The evaluation is an attempt to derive benefits based on some reasonable certainty of use of Lake Kemp/Lake Texoma and Red River water currently and in the future.

**Discussion:** Many parts of the GRR will be based on previous studies and reports. The GRR report must fully explain the data and analyses in a concise manner; backup information and supplemental studies should be provided to support the conclusions and recommendations of the report and appendices.

**Required Action:** The District will insure that the GRR Report is a stand-alone document. Information derived from previous reports will be fully explained and supported in the GRR. Information from reports by others, such as information from the Texas Water Plan or reports prepared by contractors or others and utilized for this study will be included if appropriate. Some backup reports will be provided on CD-ROM.

**2. Agriculture Analyses**.

**Comment:** The benefits appear to be based on the difference in net income between current farming practices in the without condition and optimum farming practices in the with project condition. It is also noted that an optimum w/o and optimum with condition net income differential is also presented. However, a more realistic measure of benefits would be a comparison of with project net income to without project net income based on the same level of current practices to optimum practices. For example, if current w/o condition practices are 70% of optimum then it is reasonable to assume that in the with project condition, farming practices will be 70% of optimum. It is recognized that prior analyses used the optimum to optimum comparison. However, such analyses do not capture such issues as risk management practices of landowners/farmers, or the fact that some owners may be absentee and have no interest in crop production but rather use the land for other purposes.

**Response:** Concur. The draft report will address the concerns regarding a less than optimum solution to the without project and with project conditions. The with-project condition anticipates that farming decisions will be based on economics. The current irrigated land use in the irrigation district is about 15,000 acres. The model maximizes returns to these lands and the remaining dryland acres. For the optimal solution, the model maximizes returns over the irrigable land area constrained by water quality and quantity. The risk management practices of landowners/farmers will be discussed in the draft report. As discussed in the Texas A&M report(page 9), the model requires acreage and irrigation installation decisions to be made before the uncertain states of salinity and prices are known. The inventory of land available for irrigation was revised from previous analyses. Available irrigable land is restricted to land currently irrigated(crops or pasture) plus dryland acres that are currently being cropped. These lands had to have characteristics that would have low or moderate land conversion costs, appropriate soil types, proximity to the river or canal, lift requirements, slope requirements, and size of parcel, among other factors. Total lands available for irrigation are about 100,000 acres, with less than 60,000 actually utilized in the optimal solution.

**Discussion:** The existing agricultural economic model has a significant amount of risk and uncertainty built into it and is a more conservative approach to future with-project optimization than has previously been presented. Development of additional analyses is not recommended because of the efficiency of current irrigation practices; there is about 3% difference in the without project optimum irrigation and the current without project condition.

**Required Action:** The District will insure that the efficiency of current irrigation practices and the analysis of optimum with and without project conditions are thoroughly addressed in the GRR.

**3. Environmental Impacts**.

**Comment**: It is highly recommended that during preparation of the draft report and prior to it's distribution, information pertaining to environmental impacts be shared with and explained to interest state and Federal resource agencies so there will be a good understanding of how this "scaled-back" project is different than the entire authorized plan for the Red River Basin, and to help preclude "surprises".

**Response:** Concur. Tulsa District has had and will have an ongoing work relationship with the Federal resource agencies. For the most part, data reviewed by these agencies is provided by the District. These agencies are kept informed of the District's studies.

**Discussion:** Project stakeholders include State resource agencies, as well as Federal agencies, and local users. The District informed stakeholders that the District was conducting studies for the Wichita Basin only and has continually coordinated study efforts and findings. To date, no opposition to the project has surfaced from the resource agencies. However, some comments and concerns have been raised by the USFWS, but the state of Texas has committed support to the project if proper environmental safeguards are included in the project. Control at Area X is part of the NED, and recommended, plan and will cause the stream to be dry for longer periods of time than occur naturally. This is expected to be a major concern to the resource agencies.

**Required Action:** The District will continue to coordinate with stakeholders and will follow the appropriate processes to complete the EIS.

**4. Recommendations/Budget Priorities.**

**Comment:** In light of the history of this project relative budgetary priorities, the teleconference should discuss the characteristics of any conclusions/recommendations to be included in the draft report.

**Response:** Concur. Conclusions and recommendations will be discussed at the AFB.

**Discussion:** The Wichita River Basin portion of this project was authorized for construction in 1966 (SD 110, PL 89-789 - Areas VII, VIII, and X authorized) and is partially constructed. The purpose of the GRR is to demonstrate economic justification for completing construction of remaining features in the Wichita River Basin portion of the project and to insure that the potential environmental impacts are known and documented. The GRR recommendations will not include a recommendation for project authorization, as it is not required. The GRR recommendations will be in accordance with current administration policy. At a March 13, 2001 meeting with Congressman Thornberry, TX-13, the Corps indicated support for the study but noted that the GRR was being conducted at the request of the ASA(CW) and that future support for the project would depend on Administration policy.

**Required Action:** HQUSACE Planning and Policy personnel will contact the office of the ASA(CW) to request information on current policy recommendations for the project.

**5. Real Estate Plan.**

**Comment:** The draft report should include a Real Estate Plan generally in accordance with ER 405-1-12. It is also noted, that the summary (Tab B) indicates in paragraph 2, ..."all lands for terrestrial environmental mitigation were previously acquired." It further states that appropriate additional mitigation will be necessary due to unavoidable aquatic impacts; however, there is no indication in the report to delineate what additional lands or costs will be necessary. It will be necessary for the draft report to define and delineate what lands and their appropriate costs will be required to properly evaluate the real estate impacts on the project.

**Response:** Concur. A real estate plan will be incorporated into the draft report. Further discussion should take place at the AFB.

**Discussion:** The Real Estate Plan should be done as discussed in ER 405-1-12.

**Required Action:** The District will include the Real Estate Plan in the GRR in accordance with Chapter 12, Section 16 of ER 405-1-12. The plan will be incorporated into the Engineering Appendix.

DEPARTMENT OF THE ARMY
SOUTHWESTERN DIVISION, CORPS OF ENGINEERS
1100 COMMERCE STREET
DALLAS, TEXAS 75242-0216

REPLY TO
ATTENTION OF:

CESWD-CMP-P (1105)

11 JUN 2001

MEMORANDUM FOR Commander, Tulsa District, ATTN: CESWT-PE-P

SUBJECT: Wichita Basin, Texas, Alternative Formulation Briefing - Project Guidance Memorandum

The subject Project Guidance Memorandum is enclosed for your information and action. If you have any questions, please contact Mr. Peter Shaw, CESWD-CMP-P, at (214)767-2312.

Encl

WILLIAM DAWSON, P.E.
Director, Civil Works and
Business Management
Directorate

The principal ER that guides the Corps of Engineers planning process is ER 1105-2-100, Planning Guidance Notebook, dated 22 April 2000, U.S. Army Corps of Engineers. Appendix A of ER 1105-2-100 contains references to the applicable statutes, public laws, executive orders, and engineering regulations that guide preparation of Corps feasibility studies.

Additional references that will be utilized during the completion of work tasks include the following:

EC 1105-2-208, "Preparation and Use of Project Management Plans," 23 December 1994, U.S. Army Corps of Engineers.

EC 1165-2-203, "Technical and Policy Compliance Review," Department of the Army, U.S. Army Corps of Engineers, 15 October 1996.

ER 1110-2-1150, "Engineering and Design of Civil Works Projects", 31 August 1999.

ER 5-1-11, "Program and Project Management Regulation," Department of the Army, U.S. Army Corps of Engineers, 17 August 2001.

CECW-PM, Planning Guidance Letter 97-1, "WRDA 96 Implementation," 19 November 1996, U.S. Army Corps of Engineers.

CECW-PE, Planning Guidance Letter 97-10, "Shortening the Planning Process," 26 March 1997, U.S. Army Corps of Engineers.

<u>Economic and Environmental Principles and Guidelines for Water and Related Land Resource Implementation Studies</u>, 1983.

<u>Economic and Environmental Consideration for Incremental Cost Analysis in Mitigation Planning</u>, IWR Report 91-r-1, 1991.

# WICHITA RIVER CHLORIDE CONTROL

## LOW FLOW, CONCENTRATION DURATION, AND LAKE KEMP ANALYSIS

**Swift Water Resources Engineering, LLC**
**December 7, 2001**

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# CONCENTRATION DURATION AND LOW FLOW ANALYSIS

## INTRODUCTION

### Background

Studies to control naturally occurring salt emissions in the Arkansas and Red River Basins began in 1957 when Congress directed the U.S. Public Health Service (PHS) to locate the major sources of salt emissions in those basins. Ten major sources were located in the Red River Basin and were identified as Areas V, VI, VII, VIII, IX, X, XI, XIII, XIV, and XV. A survey report was completed in 1966, which recommended that further studies be made on chloride control plans at the salt sources on the Wichita River portion (Part I), which includes Areas VII, VIII, and X. Part I was authorized by Congress in 1966, and pre-construction planning was initiated in 1968. Detailed studies for the three areas in the Wichita River Basin were completed in 1972 culminating in General Design Memorandum No. 3 (GDM #3), Chloride Control, Part 1. In 1974, the Water Resources Development Act provided special authorization to construct control measures at Area VIII on the Wichita River. In 1976, GDM #25 was submitted recommending control measures for the Wichita and Red River areas.

Construction on Area VIII began in 1979 and was completed in 1983. The project became fully operational in May 1987. The Area X pump house and low flow dam have been completed, but the pipeline to Truscott Brine Lake has not been completed. Construction of the remaining portions of Part I, Areas X and VII, was delayed due to growing concerns about the economic benefits and environmental impacts of the project. At the request of the Secretary of the Army, an effort was initiated in 1997 to reevaluate the project.

In the process of identifying the general areas of salt pollution, the PHS set up a system of gages to record daily flows and specific conductance. The PHS collected data during Water Years (WY) 1960-1967. The U.S. Army Corps of Engineers (COE) retrieved the archived PHS data and used it in this study.

Included in the COE assignment was a more finite location of the major source areas. This was accomplished by making field trips to obtain flow rates and grab samples for water quality analysis along the streams in the areas where the PHS had located the source areas. This data can be found in GDM #3.

The United States Geological Survey (USGS) also collected water quality and flow data used in this study. Prior to 1967, they were involved primarily in collecting flow data in the Wichita River Basin. When the PHS discontinued collecting water quality data, the USGS picked up the work at most locations.

**Alternatives Investigated**

Five project alternatives were identified and are listed below. The same alternatives were used by Texas A&M to evaluate the economic benefits of the project.

Plan I - Natural Conditions
Plan II - Area VIII in operation (existing conditions)
Plan III - Areas VII & VIII in operation
Plan IV - Areas VIII & X in operation
Plan V - Areas VII, VIII, & X in operation

**Hydrologic Reaches**

Hydrologic reaches used in this study were established from examination of the gages available within the study area. Hydrologic reaches are independently defined and may differ from economic and environmental reaches. Table 1 presents the hydrologic reaches used in this study.

**TABLE 1**

**HYDROLOGIC REACH DEFINITIONS**

| Hydrologic Reach | Gage | River | Description |
|---|---|---|---|
| Reach 1 | Hosston | Red | |
| Reach 5 | Denison | Red | Denison gage upstream to Cooke County line |
| Reach 6 | Gainesville | Red | East Cooke county line to West Cooke County line |
| Reach 7 | Terral | Red | Cooke/Montague County line to mouth of Wichita River |
| Reach 8 | Wichita Falls | Wichita | Mouth of Wichita River to Lake Diversion |
| Reach 9 | Mabelle | Wichita | Lake Diversion upstream to the confluence of the North and South Wichita Rivers |
| Reach 10 | Truscott | Wichita | North and Middle Wichita Rivers upstream from the confluence of the North and South Wichita Rivers |
| Reach 11 | Benjamin | Wichita | South Wichita River upstream from the confluence of the North and South Wichita Rivers |

## Period of Record

The stream flow data used during the design phase of this project, outlined in the "Background" (page 1), were from WY 1962-1970. As part of the Wichita Basin Reevaluation direction to review all data and methodologies, additional data were identified for WY 1971-1998. The WY 1962-1970 study period was considerably drier than the WY 1987-1997 period. It was appropriate to combine the periods to better represent basin hydrology and water quality. A period of record of October 1961 through September 1998 was chosen because it included the original study period and the wetter years of 1987-1998. The resulting combined data set encompassed very dry periods and very wet periods.

## Study Method

To develop concentration duration curves and tables, the following procedure was used. Flow and specific conductance data were obtained from published records. Specific conductance data were used to obtain chloride (Cl), sulfate ($SO_4$), and total dissolved solids (TDS) concentrations. Regression equations developed by the PHS/USGS were used to convert specific conductance to Cl, $SO_4$, and TDS concentrations. Loads were computed from flow and concentration data.

Two programs were developed for this study - the Low Flow Dam Routing Program and the Low Flow Routing Program. The Low Flow Dam Routing Program is a reservoir routing program used at brine collection areas to route flow and water quality data. It determines the pumped flow, the pumped water quality , and the flow that passes the low flow dams. The Low Flow Routing Program was designed to route resulting flow (flows minus holdouts) downstream and compute modified flow at downstream gages.

## Study Sequence

The steps used in this study are sequential and make up the main topics of this report.

- Recorded flow and water quality data
- Synthesized data
- Man-made chloride load
- Low Flow Dam Routing
- Low Flow Analysis
- Concentration Duration Analysis

# RECORDED FLOWS AND WATER QUALITY DATA

## Data Available For Study

The daily-recorded data used are presented in Appendix C, Table 1. Figure 1 in Exhibit A shows the locations of gages along with the major brine source areas. Figures 2 and 3 in Exhibit A present the Table 1 information in graphic form. Figure 2 shows the flow data, and Figure 3 shows the water quality data. By analyzing Figures 2 and 3, the major gages for this study were observed to be the Benjamin gage on the South Wichita River, the Truscott gage on the North Wichita River, and the Mabelle gage on the Wichita River below Lake Kemp. In this report, loads refer to quantities in terms of tons/day (T/D). Concentrations refer to milligrams per liter (mg/l), and flows refer to rates of flow in cubic feet per second (cfs).

The above gages had continuous recorded flow records for the entire study period. They also had continuous specific conductance records for 90% of the study period at the Truscott and Mabelle gages. The longest continuous unrecorded period is approximately 2 years at these two gages.

## Water Quality Conversions

Daily concentration was computed using daily conductivity measurements. The method generally used was a regression equation with coefficients developed by the USGS for each individual gage. After daily concentration was computed, daily loads were estimated. Monthly total load was computed and compared to published monthly totals to validate the approach. Where there were missing regression constants, other methods were used such as conductance-concentration correlations using USGS published grab samples. Appendix 1 describes the steps used to compute daily concentrations at various gages when the above-described method could not be applied. Tables 1 and 2 in Appendix A summarize the regression constants used to convert the daily conductivities to Cl, $SO_4$, and TDS concentrations. Data prior to 1970 were used for this study and may be found in GDM #3 of the Red River Chloride Control Study.

# SYNTHESIZED DATA

## Discussion

For areas at or above Lake Kemp, missing data at the major gages and source areas were synthesized to obtain a full period of data. The major gages were used to keep the Cl, $SO_4$, and TDS loads throughout the basin in balance. For instance, when flow and Cl concentration were synthesized at Areas VII and X, the total computed Cl load was checked to make sure it was less than load at the Truscott gage.

## Method

Most of the synthesized data were computed using the following steps.

- Flow data were available at the major gages, and upstream flow was computed using a drainage area ratio or a runoff ratio.
- Cl and $SO_4$ concentration data were computed using flow-concentration correlation curves.
- TDS concentration data were computed using a relationship of NaCl and $CaSO_4$. Most of the Cl combines with Sodium (Na) to form Sodium Chloride (NaCl), and the $SO_4$ combines with Calcium (Ca) to form Calcium Sulfate ($CaSO_4$). To determine the amount of NaCl in the water, the Cl concentration in mg/l can be multiplied by 1.6. A factor of 1.4 times the $SO_4$ concentration in mg/l will estimate the concentration of $CaSO_4$ in the water. Since there were gages at all three salt source areas at one time or another during the period of record, a relationship of the $CaSO_4$ + NaCl to TDS was computed at each gage. This value generally came out to be .90 to .97. This means that 90-97% of the constituents in the water are made up of $CaSO_4$ + NaCl. Therefore, the TDS was computed as $(1.6*Cl+1.4*SO_4)/.90$ (or .97, etc).

Appendix B contains a detailed description of the computations used to synthesize the flow and load data at Areas VII, VIII, and X, Truscott, and Mabelle gages.

## MAN-MADE CHLORIDE LOADS

### General

Man-made pollution was determined from an analysis of the USGS water quality data. Magnesium chloride ($MgCl_2$) is a product of oil field drilling and oil production. Excess Cl atoms not associated with Na (sodium) can combine with Magnesium (Mg). After determining the amount of Cl atoms needed to go with the available Na atoms, the excess Cl atoms can combine with Mg atoms to form $MgCl_2$. Using all the samples available at a gage and taking a flow/Cl weighted average of all the samples, the maximum percent of total Cl of oil field origin can be estimated.

### Seymour Analysis

The Seymour gage, which is the inflow gage into Lake Kemp, was analyzed for man-made pollution using 1996-1997 USGS water quality data. The computations are tabulated and shown in Table 2. Using this analysis, it was estimated that approximately 5% of the Cl load entering Lake Kemp was man-made.

**TABLE 2**

**ESTIMATED MAN-MADE POLLUTION**

| | | Atomic Weights | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 24.32 | 22.99 | 35.46 | | | | | |
| | | From USGS | | | | | | | |
| Date | Flow | (Mg) | (Na) | (Cl) | Cl Required For Na | Excess Cl | Amount of Mg Needed For Excess Cl | % of Total Cl in MgCl | Flow x Cl x % of Cl |
| 10/30/96 | 52.0 | 140 | 2,000 | 3,300 | 3,085 | 215 | 148 | 6.2 | 10,614.7 |
| 11/21/96 | 39.0 | 190 | 2,500 | 4,000 | 3,856 | 144 | 99 | 3.6 | 5,615.1 |
| 01/15/97 | 42.0 | 180 | 2,300 | 3,900 | 3,548 | 352 | 242 | 6.7 | 11,022.9 |
| 02/19/97 | 29.0 | 180 | 2,400 | 3,900 | 3,702 | 198 | 136 | 5.1 | 5,748.3 |
| 03/27/97 | 34.0 | 204 | 2,420 | 3,900 | 3,733 | 167 | 115 | 4.3 | 5,690.5 |
| 04/24/97 | 79.0 | 104 | 1,100 | 1,800 | 1,697 | 103 | 71 | 5.7 | 8,164.6 |
| 05/08/97 | 142.0 | 151 | 1,140 | 1,900 | 1,758 | 142 | 97 | 7.5 | 20,114.7 |
| 05/22/97 | 267.0 | 89 | 585 | 870 | 902 | -32 | -22 | 0.0 | 0.0 |
| 06/12/97 | 93.0 | 152 | 7 | 2,200 | 11 | 2,189 | 1,501 | 10.1 | 20,611.1 |
| 07/31/97 | 22.0 | 176 | 2,240 | 3,600 | 3,455 | 145 | 99 | 4.0 | 3,190.0 |
| 09/03/97 | 31.0 | 146 | 1,850 | 3,100 | 2,853 | 247 | 169 | 6.9 | 6,599.2 |
| 09/07/97 | 51.0 | 99 | 1,260 | 2,100 | 1,943 | 157 | 107 | 6.9 | 7,361.7 |
| | | | | Flow*Cl Weighted Average | | | | 5.6 | 104,733.0 |

## LOW FLOW DAM ROUTINGS

Computed daily flow and water quality data were routed through the low flow dams at Areas VII, VIII, and X with the following guidelines. Stream flow up to 10 cfs over the pump rate was pumped to Truscott Brine Lake. When inflow exceeded the limit of 10 cfs over the pump rate, no pumping would occur, and flow would pass downstream. The average pumped flow is found in Table 3. It should be pointed out that the flow pumped from May 1987 to October 1998 at Area VIII reflects actual conditions.

## LOW FLOW ANALYSIS

### Purpose

Information was required to determine the effects of project alternatives on low flow at points downstream of the low flow dams. A program was developed to compute modified flow and stage at downstream gages based on given upstream collected and pumped flow. The program generated daily modified stage data and provided the duration of drawdown events with flow below 1 cfs and 0 cfs.

### Overview of the Method

The logic behind this routing method stems from the fact that the whole alluvial floodplain is involved in the mechanics of flow modifications. The computations involved in developing a model to determine modified flows must consider this component. Therefore, items such as porosity of alluvium, volume of alluvium, surface water stream rating curves, flows, etc., are necessary in the computation of modified flows. Assumptions were made that the cross section of the alluvium is rectangular; therefore, the reduction in stage will be a constant amount based on average upstream pumped flow (holdouts). The primary source of holdouts used in this program for areas above Lake Kemp are flows pumped from the low flow dams. For areas below Lake Kemp, the primary source of holdouts is irrigation. Irrigation season extends from May to September. Irrigation water not returned to the river is considered a holdout. Excess irrigation runoff, return flow, was incorporated in the low flow analysis.

### Assumptions Made

The following assumptions were made in development of the program:

- The water level in the alluvium is equal to the water level in the river.
- The stream and alluvial volumes are computed using the same method, i.e., the porosity values are the same (rather than 100% for the stream). The error is minor when the volume of the alluvium is compared to the volume in the river. This assumption tends to lower the estimates of low flow.
- The cross section of the alluvium was considered rectangular.
- Daily low flow dam holdouts used is an average for the actual period of operation (1962-1998).
- The alluvial stage reduction is based on alluvial volume. The alluvial volume and holdouts are constant; therefore, a constant daily stage reduction can be computed based on holdouts.

- All municipal and industrial and irrigation water used in Reach 8 is taken out of Lake Kemp storage. Irrigation water used in Reaches 6 and 7 is removed directly from the Wichita River/aquifer system.
- Using the Low Flow Routing Program to route holdouts from the low flow dams to Lake Kemp, it was found that the reduction in flow was very small (less than 0.2% average). Based on this finding, it was assumed that the change in flow would have a negligible effect on final modified concentrations. Therefore, a percent total reduction in load was used to estimate the modified concentration data. This eliminated inherent routing ambiguities and errors.
- Since the flow reductions due to project implementation were negligible, the assumption was made that movement of the loads through the basin would result in the same distribution at points downstream reduced by a factor of the holdout. This assumption was made to simplify duplicating the phenomena of Cl loads being stored in the alluvium during low flow periods and flushed out during high flow periods.

**Low Flow Program Development**

The reduction in flow each day is computed as the sum of the daily reduction and the cumulative reduction. The daily reduction is a constant holdout applied each day and is computed as a reduction in stage. For extended drawdown periods, the drawdown has the cumulative effect of reducing the stage based on the previous days' reduction. The low flow program uses a cumulative reduction in flow, in addition to the normal reduction, to determine day-by-day modifications in flow. The following steps are used to compute the reduction in flow:

- Compute the <u>Stage</u> from the daily gage flow and rating table.
- Compute <u>Today's Shortage/Recharge</u> = flow – holdouts.
- Recharge the Aquifer. Recharge of the aquifer is relatively simple and straightforward. If the flow for any day or consecutive days is greater than the total drawdown amount minus holdouts, the aquifer has been recharged. The total drawdown is the summation of the deficit of daily flows. A deficit of daily flow is a condition when the holdouts or pumped flows are greater than the daily flow. For example, if the total drawdown is 100 day-second-feet (DSF) and the flow is 100 cfs with the pumped flow at 10 cfs, the new computed total drawdown would be 100 - (100-10) = 10 DSF. The 100-10 represents an excess above the required 10 cfs pumped that is available to recharge the aquifer. If the next day's flow is 20 cfs or more (10 cfs needed for pumping and 10 DSF required to fill the remaining drawdown deficit), the aquifer will be completely recharged.
- <u>Total Flow Shortage</u> = Previous Summation + Today's Shortage/Recharge (when this value exceeds 0, it is set to 0).
- Compute <u>Today's Stage Reduction</u> using the Total Flow Shortage and the Stage Reduction.
- Compute <u>New Modified Stage</u> = Original Stage (first step, above) minus Today's Stage Reduction computed in #4, above, minus the Normal Stage Reduction.

- Compute <u>Final Modified Flow</u> using the New Modified Stage and rating table.

**Data Used in the Analysis**

Data used by the program range from constant or non-changing data, such as floodplain areas and porosities, to variables, such as annual irrigation requirements. The following paragraphs and tables define the types and values of data used.

1. Flows pumped from the low flow dams are shown in Table 3.

**TABLE 3**

**FLOWS PUMPED FROM THE LOW FLOW DAMS**

| Source Areas | | | |
|---|---|---|---|
| | VIII | | |
| VII | Prior to May 1987 | After May 1987 | X |
| 10.2 | 5.4 | 6.2 | 4.8 |

2. Properties of the alluvial aquifer were obtained from a previous COE report on the Wichita River Basin. Porosity and area of the alluvial aquifer by reach are listed in Table 4.

**TABLE 4**

**ALLUVIAL AQUIFER POROSITY AND SURFACE AREA BY REACH**

| Hydrologic Reach No. | Porosity | Area (acres) |
|---|---|---|
| 6 | 0.425 | 56,236 |
| 7 | 0.425 | 44,250 |
| 8 | 0.425 | 33,088 |
| 9 | 0.430 | 18,490 |
| 10 | 0.430 | 24,531 |
| 11 | 0.430 | 21,792 |

3. Daily flows at a gage and a rating table for the gage.

4. The data in this section were derived from the Texas Agricultural Experiment Station report “Analysis of the Wichita River Portion of the Red River Chloride Control Study”, dated September 2000.

a. Irrigation return flow was calculated from leaching fractions presented in the report. The percent return flows by plan are shown in Table 5 along with a description of each plan.

**TABLE 5**

**IRRIGATION RETURN FLOW**

| Plan No. | Description | Irrigation Return Flow (%) |
|---|---|---|
| 1 | Natural | 43.5 |
| 2 | With Area VIII Only | 39.8 |
| 3 | With Areas VII & VIII In | 31.0 |
| 4 | With Areas VIII & X In | 38.3 |
| 5 | With Areas VII, VIII & X In | 26.5 |

b. The Texas A&M study also provided expected future irrigation requirements. Table 6 depicts the annual irrigation requirements by reach. Note that some plans require less water than the existing or natural plan (Plan 1). This is because as successive plans are implemented, water quality improves and less water is required for irrigation. Less water is actually required to leach excess salts from the soil.

**TABLE 6**

**ANNUAL IRRIGATION REQUIREMENTS BY REACH (acre-feet)**

| Year | Plan | Hydrologic Reach | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 2005 | 1 | 0 | 62,301 | 288 | 80,000 | 0 | 0 | 0 |
| | 2 | 0 | 58,429 | 270 | 75,028 | 0 | 0 | 0 |
| | 3 | 0 | 64,110 | 236 | 183,831 | 0 | 0 | 0 |
| | 4 | 0 | 71,627 | 264 | 73,220 | 0 | 0 | 0 |
| | 5 | 0 | 60,131 | 221 | 172,420 | 0 | 0 | 0 |
| 2015 | 1 | 0 | 62,703 | 0 | 80,000 | 0 | 0 | 0 |
| | 2 | 0 | 58,806 | 0 | 75,028 | 0 | 0 | 0 |
| | 3 | 0 | 64,110 | 236 | 183,831 | 0 | 0 | 0 |
| | 4 | 0 | 71,627 | 264 | 73,220 | 0 | 0 | 0 |
| | 5 | 0 | 60,131 | 221 | 172,420 | 0 | 0 | 0 |
| 2025 | 1 | 0 | 62,703 | 0 | 80,000 | 0 | 0 | 0 |
| | 2 | 0 | 58,806 | 0 | 75,028 | 0 | 0 | 0 |
| | 3 | 0 | 64,110 | 446 | 183,831 | 0 | 0 | 0 |
| | 4 | 0 | 71,627 | 499 | 73,220 | 0 | 0 | 0 |
| | 5 | 0 | 60,131 | 419 | 172,420 | 0 | 0 | 0 |
| 2035 | 1 | 0 | 62,703 | 0 | 80,000 | 0 | 0 | 0 |
| | 2 | 0 | 58,806 | 0 | 75,028 | 0 | 0 | 0 |
| | 3 | 0 | 64,110 | 446 | 183,831 | 0 | 0 | 0 |
| | 4 | 0 | 71,627 | 499 | 73,220 | 0 | 0 | 0 |
| | 5 | 0 | 60,131 | 419 | 172,420 | 0 | 0 | 0 |

**Low Flow Analysis Results**

**Above Lake Kemp**. Resource agencies expressed concerns about the impact of the project on naturally occurring low flows on the Wichita River. Their main concern was the impact of increased low flow periods on indigenous threatened and endangered species.

The computer routing model was designed to simulate the effects of the different alternatives of Wichita River chloride control. The low flow routing model calculated the number of low flow days as a result of upstream holdouts. The model also calculated actual dates during the period of record of low flow days based on specific modified conditions. Table 7 lists the number of zero flow days under natural conditions and the four project alternatives. Please note that Reach 10 is affected only by Areas VII and X. Area VIII was included for simplicity. Table 8 lists the percent of low flow days during the period of record at each gage for each project alternative. The largest percent increase in low flow days is seen in Reach 10 as a result of combined implementation of Areas VII and X. Minor percent increases result from completion of Areas VII and X separately. Zero flow days in Reach 11 increase by only 0.27% from natural conditions as a result of implementation of Area VIII. This indicates that there is a significant contribution from groundwater in this reach. Minor percent increases are seen in the number of zero flow days in Reach 9 indicating that flow from the upper reaches of the Wichita River Basin is a very small percentage of the total flow entering Lake Kemp and Reach 9.

**TABLE 7**

**LOW FLOW DAYS**

| Location | Plan | Average Q | No. of Days | |
|---|---|---|---|---|
| | | | =/<0 | =/<1 |
| Benjamin | Natural | 42.9 | 1,195 | 1,821 |
| | With Area VIII | 42.5 | 1,230 | 2,055 |
| Truscott | Natural | 66.9 | 2 | 201 |
| | With Area X | 66.5 | 125 | 211 |
| | With Area VII | 64.8 | 334 | 485 |
| | With Areas VII & X | 62.2 | 1,131 | 1,350 |
| Lake Kemp | Natural | 228.2 | 109 | 181 |
| (1.42 x Seymour) | With Area VIII | 228.1 | 109 | 182 |
| (12/59-7/79 WY)* | With Areas VIII & X | 228.0 | 110 | 184 |
| | With Areas VII & VIII | 227.8 | 114 | 196 |
| | With Areas VII, VIII, & X | 227.6 | 114 | 202 |

*Seymour gage data were multiplied by a factor of 1.42 to simulate inflows into Lake Kemp. Seymour gage data were available for 12/59 – 7/79.

## TABLE 8

### UPPER WICHITA RIVER LOW FLOW ANALYSIS
### PERCENT OF LOW FLOW DAYS IN PERIOD OF RECORD
### Flow £ 0 cfs

| | Reach 6 | Reach 7 | Reach 8 | Reach 9 | Reach 10 | Reach 11 |
|---|---|---|---|---|---|---|
| Natural Conditions | 0.0 | 0.0 | 0.0 | 1.47 | 0.015 | 8.84 |
| W/Area VIII | 0.0 | 0.0 | 0.0 | 1.47 | NA | 9.11 |
| W/Areas VII & VIII | 0.0 | 0.0 | 0.0 | 1.54 | 2.47 | NA |
| W/Areas VIII & X | 0.0 | 0.0 | 0.0 | 1.49 | 0.93 | NA |
| W/Areas VII, VIII, & X | 0.0 | 0.0 | 0.0 | 1.49 | 8.37 | NA |

* Period of Record 10/61 – 9/98, 13,505 days.
**Period of Record 12/59 – 9/79, 7,604 days.
NA = Not available.

A review of the period of record for Reaches 6, 7, and 8 indicates that there have been no zero flow days under natural conditions. Review of the low flow routing output for these downstream reaches reveals that implementation of all project alternatives will result in no reduction in flow. This can be attributed to increased irrigation return flow and decreased irrigation water usage due to improved water quality. Minor increases in flow are seen as a result of projected increases in irrigation and irrigation return flow. Minimum flows for the downstream reaches are listed on the flow duration curves in Appendix B.

**Below Lake Kemp**. A review of the period of record for Reaches 6, 7, and 8 indicates that there have been zero low flow days under natural conditions. Review of the low flow routing output for the downstream reaches reveals that implementation of all project alternatives will result in no reduction in flow. Minor increases in flow are seen as a result of projected increases in irrigation and irrigation return flow. Minimum flows for the downstream reaches are listed on the attached flow duration curves.

**Flow Duration Data**. Flow duration data were determined for natural conditions and each project alternative. The differences in flow between natural conditions and each alternative were very minor. As a result, the duration curves plotted on top of each other. Table 9 presents the duration data.

**TABLE 9**

**FLOW DURATION RESULTS**

| Gage Location | Plan | Flow Duration Percent of Time Equaled or Exceeded | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **5** | **10** | **20** | **50** | **80** | **90** | **95** | **99** |
| Benjamin Reach 11 | 1 | 820.3 | 116.2 | 49.1 | 21.0 | 7.6 | 2.2 | 0.3 | 0.0 | 0.0 |
| | 2 | 820.0 | 116.0 | 49.0 | 20.9 | 7.2 | 1.8 | 0.2 | 0.0 | 0.0 |
| | 3 | Same as Plan 2 | | | | | | | | |
| | 4 | Same as Plan 2 | | | | | | | | |
| | 5 | Same as Plan 2 | | | | | | | | |
| Truscott Reach 10 | 1 | 1,030.0 | 143.0 | 67.0 | 38.0 | 20.0 | 11.0 | 7.5 | 4.8 | 0.7 |
| | 2 | Same as Plan 1 | | | | | | | | |
| | 3 | 1,029.4 | 142.6 | 65.7 | 37.7 | 19.8 | 9.8 | 4.8 | 1.8 | 0.0 |
| | 4 | 1,029.8 | 142.9 | 66.9 | 37.9 | 19.9 | 11.4 | 7.5 | 4.8 | 0.1 |
| | 5 | 1,029.1 | 140.6 | 65.6 | 37.6 | 18.7 | 7.3 | 1.0 | 0.0 | 0.0 |
| Lake Kemp Reach 9 | 1 | 4,004.4 | 815.1 | 313.8 | 125.0 | 42.6 | 18.5 | 9.1 | 3.5 | 0.0 |
| | 2 | 4,004.0 | 814.9 | 313.7 | 124.9 | 42.5 | 18.5 | 8.9 | 3.5 | 0.0 |
| | 3 | 4,003.2 | 814.5 | 313.5 | 124.7 | 42.4 | 18.4 | 8.4 | 3.2 | 0.0 |
| | 4 | 4,003.7 | 814.8 | 313.6 | 124.8 | 42.5 | 18.4 | 8.8 | 3.7 | 0.0 |
| | 5 | 4,002.8 | 814.3 | 313.4 | 124.6 | 42.3 | 17.0 | 8.1 | 2.9 | 0.0 |
| Wichita Falls Reach 8 | 1 | 2,909.0 | 1,190.0 | 549.0 | 188.1 | 82.0 | 44.0 | 34.0 | 27.0 | 17.0 |
| | 2 | 2,909.0 | 1,188.9 | 549.0 | 187.5 | 81.6 | 44.0 | 34.0 | 27.0 | 17.0 |
| | 3 | 2,909.8 | 1,190.0 | 549.9 | 189.9 | 82.8 | 45.0 | 34.0 | 27.0 | 17.0 |
| | 4 | 2,909.0 | 1,188.4 | 548.6 | 187.1 | 81.4 | 44.0 | 34.0 | 27.0 | 17.0 |
| | 5 | 2,909.5 | 1,190.0 | 549.9 | 189.0 | 82.0 | 44.9 | 34.0 | 27.0 | 17.0 |
| Terral Reach 7 | 1 | 30,798.0 | 10,005.0 | 5,760.0 | 2,630.0 | 653.0 | 299.0 | 205.0 | 165.0 | 117.0 |
| | 2 | 30,788.0 | 10,000.0 | 5,758.1 | 2,630.0 | 652.1 | 298.0 | 204.7 | 164.7 | 117.0 |
| | 3 | 30,845.0 | 10,013.0 | 5,760.0 | 2,630.0 | 653.7 | 299.3 | 205.3 | 165.0 | 117.4 |
| | 4 | 30,783.0 | 9,998.0 | 5,757.2 | 2,630.0 | 652.0 | 298.0 | 204.6 | 164.6 | 117.0 |
| | 5 | 30,821.0 | 10,006.0 | 5,760.0 | 2,630.0 | 653.1 | 299.0 | 205.0 | 165.6 | 117.4 |
| Gainesville Reach 6 | 1 | 43,500.0 | 13,700.0 | 7,750.0 | 3,610.1 | 971.1 | 389.0 | 253.0 | 196.0 | 130.0 |
| | 2 | 43,500.0 | 13,700.1 | 7,749.8 | 3,610.1 | 970.9 | 389.0 | 253.0 | 196.0 | 130.0 |
| | 3 | 43,500.0 | 13,790.2 | 7,750.0 | 3,614.2 | 972.3 | 389.0 | 253.0 | 196.0 | 130.0 |
| | 4 | 43,500.0 | 13,692.4 | 7,744.5 | 3,610.1 | 970.1 | 388.8 | 252.1 | 195.1 | 130.0 |
| | 5 | 43,500.0 | 13,702.7 | 7,750.0 | 3,611.2 | 971.1 | 389.0 | 253.0 | 196.0 | 130.0 |

**7-Day 2-Year Volume Duration Frequency Data**

**Method.** Seven-day, two-year frequency low flow volumes were calculated for the gages above Lake Kemp. To compute these values, the annual 7-day low flow volumes were needed. A program was written to determine the low flow volumes, which were then plotted on log-frequency paper using Beards plotting positions. To get a representative estimate at Lake Kemp, Seymour flows were used and adjusted to allow for intervening area flows between the gage and the lake.

**Results.** Table 10 presents the results of the 7-day, 2-year frequency analysis for the gages above Lake Kemp.

**TABLE 10**

**7-DAY LOW FLOW VOLUMES, 2-YEAR FREQUENCY (WY 1962-1998)**

| Location | Plan | Volume (DSF) |
|---|---|---|
| Benjamin Gage | Natural | 0 |
| | With Area VIII | 0 |
| Truscott Gage | Natural | 41 |
| | With Area X | 40 |
| | With Area VII | 32 |
| | With Areas VII & X | 22 |
| Lake Kemp (1.42*Seymour Flows (Dec 79-Sep 79) | Natural | 20 |
| | With Area VIII | 18 |
| | With Areas VIII & X | 18 |
| | With Areas VII & VIII | 17 |
| | With Areas VII, VIII, & X | 17 |

**Sensitivity Analysis.** The Wichita Falls gage has 60 years of flow records and was used for a sensitivity analysis comparing the different periods of record; WY 1939-1998; WY 1962-1998, and WY 1960-1979. The 7-day volume, 2-year frequency flow for the 60 years of record was approximately 80 DSF. The 37-year period of record was about 5 DSF less, and the 20-year period was 3-5 DSF less than the 37-year period. This comparison shows that the 37-year period of record compares well with longer and shorter periods of record. The 20-year period was not quite as good but, considering that the only other alternative was to use the 37 years of record of Lake Kemp inflows as determined by the monthly reservoir regulation charts, it gave a much better answer. The natural 7-day volume, 2-year frequency, as computed using the monthly reservoir regulation charts computed inflows, gave 8-10 DSF. Many times when inflow is less than 10 cfs, the estimated inflow is rounded off to zero. This gives a false, lower 7Q2 value. This is considerably further from the target than the 20-year period of record that was used.

## CONCENTRATION DURATION CURVE ANALYSIS

### General

Concentration duration computational methodology was similar for all gages except Reach 1, the Hosston, Louisiana, gage. Therefore, the discussion for Reach 1 was separated from the rest of the reaches. Plates showing all the concentration duration curves are in Exhibit B, with corresponding duration tables located in Exhibit C.

## Computation Methods

Due to Area VIII going online in May 1987, modification of data for Lake Kemp (Mabelle gage) and gages downstream was divided into two time periods. Prior to May 1987, all the loads pumped from Area VIII were used to determine a reduction factor. After May 1987, no additional reductions were taken from Area VIII. It was noted that there were 64.5 T/D more load going by Truscott and Benjamin gages than was recorded at the Mabelle gage prior to May 1987. These loads were assumed to be stored in the alluvium and were flushed out during the high flow periods after May 1987. An adjustment was made in the loads by assuming the average Cl load at the Mabelle gage and gages downstream prior to May 1987 was 64.5 T/D less than was recorded. The volume after May 1987 was adjusted to reflect an added volume, which would be equivalent to 64.5 T/D. Considering that T/D is a rate rather than a volume and using the difference in time periods, the rate for May 1987-September 1998 was determined to be 89.5 T/D.

## Natural Concentration Duration Curves

All gages downstream from Area VIII reflected holdouts from Low Flow Dam 8 from May 1987 on. Therefore, to obtain a natural condition, i.e., no effects of low flow dam holdouts, this gage data had to be modified to account for Area VIII holdouts. This was accomplished by increasing the daily concentrations by a ratio of the Area VIII holdouts divided by the gaged load. Final data for the study period included gaged data for October 1961 - April 1987 and new data for May 1987 - September 1998. Duration curves were computed using the final data.

## Modified Duration Curves

Modified duration curves were derived by modifying the gaged data and computing duration curves. Modification of the gaged data was accomplished by first determining the total load reduction for each gage and plan. Since the gaged data included data that had already been modified by Area VIII pumped flows as noted above, two different sets of load reductions were used at each gage based on the time period of the data. Appendix C contains more detailed information concerning the individual locations.

## Percent Error

According to the USGS, the margin of error in recorded flow and concentration data is +/- 10%. Additional duration curves were computed representing +/- 10% to represent the margin of error. The margin-of-error curves were not plotted on the Red River reaches because the difference between the natural and modified curves was so minor that it would add confusion to the plot. Future without-project conditions are expected to include brush control on 50% of the Lake Kemp Basin below the collection areas. The future without-project conditions are expected to fall within the +/- 10% margin of error curves. These additional values are shown in each duration table and curve.

**Hosston - Reach 1 Duration Curves**

Data were limited at the Hosston, Louisiana, gage. The natural and modified duration curves were changed from the original study based on a percent change between the original study and this study at Denison, Reach 5. The “original study” used was the Limited Reevaluation Report (LRR) as revised in June 1993. The following paragraphs explain the process involved.

**Natural Curves.** The following equation was used for the natural durations. For any given duration:

Ratio = New Natural Concentration @ Denison / LRR Natural @ Denison
New Natural Concentration @ Hosston = Hosston concentration from LRR * Ratio

**Modified Curves.**

1. With Areas VIII and X. This was the only modified duration curve in the LRR report that used only Wichita River source areas and it included Ross Ranch LFD, which was not included in this study.

    a. Ross Ranch Pumped Load / Total Load Reduction @ Hosston for LRR (20/201=.1) Hosston concentrations were increased by approximately 10% to reflect elimination of the Ross Ranch LFD.
    (LRR-RR) = LRR minus the Ross Ranch
    (LRR-RR) concentration @ Hosston = LLR concentration / .9
    b. Ratio1 = New Modified concentration @ Denison / New Natural concentration @ Denison
    c. Ratio2 = LRR modified concentration @ Denison / LRR natural concentration @ Denison
    d. Ratio3 = (LRR-RR) Hosston modified concentration / LRR Hosston modified concentration
    e. RatioF = Ratio1 / Ratio2 * Ratio3
    f. New Modified Concentration @ Hosston = New Natural Hosston concentration * RatioF

2. Other Plans. VIII-X = Plan with Areas VIII & X

    a. Ratio1 = New Modified concentration @ Denison/ New 8-10 concentration @ Denison
    b. Ratio2 = Ratio1 * RatioR (above)
    c. New Modified Concentration @ Hosston (for plan) = New Natural concentration @ Hosston * Ratio2

**Results**

The goal of Wichita River chloride control is to improve water quality within the Wichita River and Red River basins. To assess the effectiveness of the project, concentration duration curves were calculated for Cl, $SO_4$, and TDS for each reach and each alternative considered. Concentration duration curves are presented as Plates 1-22 in Exhibit B. Concentration duration data are also presented in Tables 1-15 in Exhibit C. Of particular interest within the study is the effect of the project on water quality at Lake Kemp and Lake Texoma. Discussion of the results of the concentration duration study will concentrate on hydrologic reaches 5 (Lake Texoma) and 9 (Lake Kemp).

Based on the period of record 1962-1998, the selected plan will remove 1,080 T/D of TDS from the upper reaches of the Wichita River Basin. Of this 1,080 T/D, 409 T/D of chlorides will be removed. Table 11 presents the daily loads for each source area and the percent removal. These data are also included in Table C-1 in Appendix C for all hydrologic reaches. Table 12 presents the effectiveness as percent removal or control for each plan.

**TABLE 11**

**PLAN EFFECTIVENESS**
**PERCENT CONTROL AT SOURCE AREAS**

| | | **Loads (Tons/Day)** | | |
|---|---|---|---|---|
| **Location** | | **Cl** | **$SO_4$** | **TDS** |
| Area VII | Natural | 244 | 87 | 539 |
| | Controlled | 195 | 63 | 419 |
| | % Control | 80% | 72% | 78% |
| | | | | |
| Area VIII | Natural | 189 | 49 | 380 |
| | Controlled | 165 | 42 | 332 |
| | % Control | 87% | 86% | 87% |
| | | | | |
| Area X | Natural | 58 | 43 | 161 |
| | Controlled | 49 | 36 | 137 |
| | % Control | 84% | 84% | 85% |

**TABLE 12**

**PLAN EFFECTIVENESS**
**PERCENT CONTROL BY PLAN**

| Location | | Loads (Tons/Day) | | |
|---|---|---|---|---|
| | | Cl | $SO_4$ | TDS |
| Plan I | Natural | 491 | 209 | 1080 |
| | | | | |
| Plan II | Controlled | 165 | 42 | 332 |
| | % Control | 34% | 20% | 31% |
| | | | | |
| Plan III | Controlled | 360 | 105 | 751 |
| | % Control | 73% | 50% | 70% |
| | | | | |
| Plan IV | Controlled | 214 | 78 | 469 |
| | % Control | 44% | 37% | 43% |
| | | | | |
| Plan V | Controlled | 409 | 141 | 888 |
| | % Control | 83% | 67% | 82% |

Lake Kemp, owned and operated by the Wichita County Water Improvement District and the city of Wichita Falls, currently supplies irrigation, industrial, and recreation water to Wichita County. The lake has not been utilized as a source of municipal drinking water due to poor water quality.

As Table 12 illustrates, Wichita River chloride control has the potential to remove 31 to 82% of the TDS load and 34 to 83% of the Cl load from the Wichita River Basin. Of particular interest in the upper Wichita River Basin is the project's impact on Lake Kemp. Under natural conditions, the Cl concentrations at Lake Kemp equal or exceed 696 mg/l 99% of the time and are greater than 1,312 mg/l 50% of the time. With implementation of the selected plan, Cl concentrations will equal or exceed 166 mg/l 99% of the time and will be greater than 318 mg/l 50% of the time. This represents a 76% reduction in Cl concentration at Lake Kemp. One of the milestones for Cl concentration reduction is the U.S. Environmental Protection Agency's (USEPA) secondary drinking water standard for Cl of 250 mg/l. The selected plan is expected to meet this secondary standard only 15% of the time. Another milestone is the Texas Natural Resource Conservation Commission's (TNRCC) secondary drinking water standard for Cl of 300 mg/l. The selected plan is expected to meet the TNRCC secondary standard approximately 40% of the time. Lake Kemp concentration duration data are presented in Table 13.

**TABLE 13**

**LAKE KEMP CONCENTRATION DURATION DATA**

| | **Natural Conditions** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Percent of Time Equaled or Exceeded** | | | | | | | | |
| | **1%** | **5%** | **10%** | **20%** | **50%** | **80%** | **90%** | **95%** | **99%** |
| Chlorides (mg/l) | 1,985 | 1,843 | 1,751 | 1,628 | 1,312 | 1,106 | 1,016 | 934 | 696 |
| Sulfates (mg/l) | 953 | 890 | 869 | 835 | 755 | 631 | 575 | 523 | 386 |
| TDS (mg/l) | 4,650 | 4,305 | 4,115 | 3,838 | 3,254 | 2,762 | 3,515 | 2,325 | 1,745 |
| | **Plan V (W/Areas VII, VIII, & X)** | | | | | | | | |
| | **Percent of Time Equaled or Exceeded** | | | | | | | | |
| | **1%** | **5%** | **10%** | **20%** | **50%** | **80%** | **90%** | **95%** | **99%** |
| Chlorides (mg/l) | 489 | 434 | 409 | 377 | 318 | 257 | 233 | 212 | 166 |
| Sulfates (mg/l) | 540 | 510 | 494 | 456 | 395 | 323 | 294 | 268 | 202 |
| TDS (mg/l) | 1,580 | 1,430 | 1,343 | 1,275 | 1,108 | 897 | 815 | 742 | 541 |

Wichita Falls is expected to begin utilizing Lake Kemp as a municipal drinking water source within the next 3 years. The current Lake Kemp water quality will require the city to treat the water using reverse osmosis to meet secondary drinking water requirements. Implementation of the selected plan will improve water quality at Lake Kemp, but treatment will still be required. Implementation of the selected plan is expected to result in reduced treatment cost for the city of Wichita Falls.

The Red River Basin has an estimated the total chloride load of 3,300 T/D. The selected plan will remove 409 T/D resulting in a 12% reduction in total chloride load for the Red River Basin. The concentration duration study revealed that under natural conditions, the Cl concentrations at Lake Texoma equal or exceed 165 mg/l 99% of the time and is greater than 345 mg/l 50% of the time. With implementation of the selected plan, Cl concentrations will equal or exceed 147 mg/l 99% of the time and will be greater than 309 mg/l 50% of the time. This represents a 10% reduction in chloride concentration at Lake Texoma. Table 14 presents Lake Texoma concentration data.

**TABLE 14**

**LAKE TEXOMA CONCENTRATION DURATION DATA**

| | Natural Conditions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| | **1%** | **5%** | **10%** | **20%** | **50%** | **80%** | **90%** | **95%** | **99%** |
| Chlorides (mg/l) | 469 | 436 | 423 | 409 | 345 | 271 | 241 | 216 | 165 |
| Sulfates (mg/l) | 315 | 301 | 289 | 273 | 228 | 164 | 146 | 129 | 91 |
| TDS (mg/l) | 1,294 | 1,234 | 1,207 | 1,166 | 995 | 791 | 722 | 634 | 474 |
| | **Plan V (W/Areas VII, VIII, & X)** | | | | | | | | |
| | **Percent of Time Equaled or Exceeded** | | | | | | | | |
| | **1%** | **5%** | **10%** | **20%** | **50%** | **80%** | **90%** | **95%** | **99%** |
| Chlorides (mg/l) | 417 | 391 | 376 | 365 | 309 | 245 | 215 | 192 | 147 |
| Sulfates (mg/l) | 296 | 283 | 273 | 257 | 217 | 155 | 138 | 123 | 87 |
| TDS (mg/l) | 1,190 | 1,136 | 1,109 | 1,075 | 921 | 730 | 665 | 582 | 435 |

## BRUSH CONTROL PROGRAM IMPACT ANALYSIS

Due to growing concern in the Wichita River Basin about the availability of water and its effect on economic growth and development, the Red River Authority of Texas in cooperation with the Texas State Soil and Water Conservation Board (TSSWCB) initiated a study to determine the feasibility of implementing a brush control and management program to increase water yield. The Texas Legislature designated the TSSWCB as the lead agency to conduct watershed studies in conjunction with the Texas Agricultural Experiment Station and Extension Service, river authorities, and other local entities.

The study was accomplished under the direction of the TSSWCB in partnership with the Red River Authority of Texas, the Texas Agricultural Experiment Station and Extension Service, the USDA Natural Resource Conservation Service (NRCS), the Blackland Research Center, and local soil and water conservation districts.

The results of the study revealed that implementation of the proposed brush control program may be expected to provide a net increase in overall watershed yield at Lake Kemp between a minimum of 27.6% to a maximum of 38.9% based on the report's estimated average inflow into Lake Kemp of 119,100 acre-feet per year.

Several resource agencies have expressed concern over the projected increase in zero flow days on the upper Wichita River after Wichita River chloride control implementation. The resource agencies were concerned that increases in zero flow days could impact species adapted to brine flows of the Wichita River. An investigation was initiated to assess the impact of the brush control program on low flow days projected for chloride control implementation.

The NRCS performed watershed modeling for the brush control program using the Soil and Water Assessment Tool (SWAT) model. The SWAT model predicts the impacts of watershed management activities on watershed yield and sedimentation of large unmeasured watersheds. The COE requested the SWAT model output for three USGS stream gaging stations within the Wichita Basin. These gages were the Truscott gage (07311700) on the North Fork of the Wichita River, the Benjamin gage (07311800) on the South Fork of the Wichita River, and the Seymour gage (07311900) on the Wichita River. The model output included flows for the with-brush condition, the without-brush condition, and the historical flows for each gage.

The low flow modeling performed to assess impacts of the chloride control project indicated that the project would have minor impacts at the Benjamin and Seymour gages. The Truscott gage, located downstream of the confluence of the Middle and North Wichita Rivers, showed the greatest increase in zero flow days with project implementation. The low flow modeling indicated that the Truscott gage would see an increase from 2 zero flow days under natural conditions to 1,131 days with Areas VII and X in operation.

A review of the SWAT model output revealed that the model under-predicted flow at the Truscott and Benjamin gages for the first few years of the model run and then matched fairly well for the remainder of the simulation. The total flow for the period of record, 1960-1998, for the with-brush condition and the historical record matched very well. The SWAT model under-predicted flows for the Seymour gages during the period of record (1960-1979).

A comparison of period of record flow totals for the historical and with-brush condition to the without-brush condition was performed for the Truscott and Benjamin gages. A flow increase factor was developed for these gages. Due to the SWAT model under-prediction of flows at the Seymour gage, a flow increase factor of 27.6% was assumed. Using the assumption that brush control would only be applied below the collection areas, a drainage area ratio was created for each gage. The drainage area ratio was applied to the total flow increase percentage to obtain a final flow increase percentage of 1.45 for the Truscott gage, 1.73 for the Benjamin gage, and 1.17 for the Seymour gage.

The final flow increase factor was used to increase historical flows used in the low flow analysis. The slope of the flow recession curves for historical flows was used to route modified flows less than 1 cfs. The brush management low flow routing model output included the number and dates of flows less than 1 cfs and 0 cfs. Using this procedure, simulation runs were made assuming 50% brush removal for the basin above Lake Kemp and below the collection areas. The simulation results are presented in Table 15.

## TABLE 15

## ZERO FLOW DAYS
## 50% BASIN BRUSH CONTROL

| | Reach 9 Lake Kemp* | Reach 10 Truscott** | Reach 11 Benjamin** |
|---|---|---|---|
| Natural | 109 | 2 | 1,195 |
| Plan V (Areas VII, VIII, & X) | 114 | 1,131 | 1,230 |
| 50% Brush Control | | | |
| Natural 27.6% | 104 | 2 | 1,062 |
| Natural – 38.9% | 104 | 2 | 1,057 |
| Selected Plan 27.6% | 113 | 614 | 1,110 |
| Selected Plan 38.9% | 112 | 440 | 1,091 |

*  Period of Record 12/59 – 9/98, 7,604 days.
**Period of Record 10/61 – 9/98, 13,505 days.

The brush control program has currently been included in Texas Senate Bill 1 and the Region B Water Plan.  Implementation of the program is expected to occur regardless of decisions made on Wichita River chloride control.  The brush control program is expected to alter future without-project conditions.  Low flow modeling was performed for the stream reaches above Lake Kemp to estimate the program's impact.  Assuming 50% program implementation for only the areas above Lake Kemp and below the collection areas, the brush management program would decrease the number of future zero flow days at the Benjamin gage by an average of 136 days (11% decrease) and 5 days at Lake Kemp (5% decrease).  Brush control at the Truscott gage is not expected to decrease future without-project low flow days.  Table 15 presents low flow data for projected future brush control without-project modeling results.

Implementation of the brush control program on the North and Middle Forks of the Wichita River have the potential of reducing the number of zero flow days at the Truscott gage from 1,131 days with Areas VII and X in operation to 614 to 440 days (average of 527 days).  This represents a reduction of 61% to 46% in the number of with-project zero flow days.  Implementation of the brush control program on the North and Middle Forks of the Wichita River is a technically feasible alternative to reducing with-project zero flow day impacts.

## LAKE KEMP ANALYSIS

The emphasis of this report has been to investigate the impacts of the chloride control project on low flows and solute concentrations in the Wichita River Basin.  The project also has the potential to impact Lake Kemp storage by decreasing inflow and increasing water use due to improved water quality.  These impacts could decrease the yield of Lake Kemp and affect future economic development in the area.  Investigation of these impacts is explained in detail in the following paragraphs.

## Lake Kemp Inflow

Based on data obtained from the COE 2000 Annual Report, the long-term average inflow for Lake Kemp is 188,600 acre-feet per year. This long-term average is based a period of record from 1924 to 2000. Average annual inflow for the period of record, 1962-1998, used in the low flow/concentration duration analysis is 177,153 acre-feet per year. A review of inflows from 1988-2000 for Lake Kemp, the period of record after construction of Area VIII, reveals an average annual inflow of 186,952 acre-feet per year. This indicates that removal of brine flows from the upper reaches of the basin has a minor affect on inflow into Lake Kemp. Potential future sedimentation impacts are evaluated in Appendix D.

## Projected Future Irrigation and M&I Impacts on Lake Kemp

Increased irrigation and municipal and industrial water usage is projected for Lake Kemp after project construction due to improved water quality. A computer routing program was developed to simulate existing conditions and future conditions after project completion. Existing and future water usage in the routing model is presented in Table 16.

**TABLE 16**

**EXISTING AND PROJECTED WATER USAGE IN LAKE KEMP**

| | Existing Water Usage (acre-feet/year) | Projected Water Usage (acre-feet/year) |
|---|---|---|
| Irrigation | 80,000 | 120,000 |
| Municipal | 0 | 11,222 |
| Industrial | 10,000 | 20,000 |
| Recreation | 5,850 | 5,850 |
| TPWD Hatchery | 2,200 | 2,200 |

The computer routing program was designed to route monthly historical inflows, evaporation, and precipitation through Lake Kemp. The period of record used was WY 1949 to CY 2000. Monthly releases were based on the existing and projected water usage listed in Table 16. The program assumed that the top of conservation pool was elevation 1145 and all storage above elevation 1145 was floodwater and immediately released. The current top of conservation pool at Lake Kemp is elevation 1144, but the lake routinely utilizes the storage from 1144 to 1145.

## Drought Contingency Requirements

The Wichita County Water Improvement District was required by Texas Senate Bill 1 to develop and implement a drought contingency plan for Lake Kemp in CY2000. The drought contingency plan created action levels that required reductions in water usage at specific elevations. The drought contingency requirements were installed in the routing program to reflect existing and future water usage conditions. The drought contingency requirements for the routing program are listed in Table 17.

**TABLE 17**

**DROUGHT CONTINGENCY WATER USAGE ASSUMPTIONS**

| | **Elevation 1145.0** | **Elevation 1123.0** | **Elevation 1114.0** | **Elevation 1109.0** |
|---|---|---|---|---|
| Irrigation | 100% | 50% | 25% | 0% |
| Municipal | 100% | 100% | 100% | 100% |
| Industrial | 100% | 100% | 100% | 100% |
| Recreation | 100% | 0% | 0% | 0% |
| TPWD Hatchery | 100% | 0% | 0% | 0% |

**Results**

Modeling runs were performed for existing conditions, selected plan with 50% brush control below Area VII and Area X collection areas and above the Truscott gage, and selected plan with 50% brush control below the collection areas at Areas VII, VIII, and X and above Lake Kemp. Elevation duration results for selected elevations are included in Table 18.

**TABLE 18**

**LAKE KEMP ELEVATION DURATION DATA**

| | **Percent of Time Equaled or Exceeded** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Elevation** | | | | | | | |
| | **1114** | **1120** | **1123** | **1125** | **1130** | **1135** | **1140** | **1144** |
| Existing Conditions | 100.0 | 100.0 | 100.0 | 99.8 | 99.3 | 91.2 | 70.1 | 29.3 |
| Existing Conditions w/50% Brush Control - 27.6% | 100.0 | 100.0 | 100.0 | 100.0 | 99.5 | 94.0 | 73.3 | 31.4 |
| Existing Conditions w/50% Brush Control – 38.9% | 100.0 | 100.0 | 100.0 | 100.0 | 99.5 | 95.9 | 74.1 | 33.3 |
| Selected Plan w/50% Brush Control @ Truscott – 27.6% | 98.9 | 89.3 | 83.1 | 75.9 | 63.3 | 48.0 | 24.7 | 10.7 |
| Selected Plan w/50% Brush Control @ Truscott – 38.9% | 98.9 | 89.9 | 83.9 | 76.7 | 63.7 | 48.6 | 25.0 | 11.4 |
| Selected Plan w/50% Basin Brush Control 27.6% | 99.3 | 91.4 | 85.2 | 78.9 | 66.5 | 51.5 | 29.4 | 13.2 |
| Selected Plan w/50% Basin Brush Control 38.9% | 99.7 | 92.4 | 88.3 | 82.1 | 69.8 | 53.8 | 32.7 | 14.3 |

Implementation of the brush control program for 50% of the area above Lake Kemp and below the collection areas will effectively change without-project future conditions. The increase in inflows as a result of the brush control program will increase elevation duration. Table 18 indicates that under existing conditions, the elevation at Lake Kemp will equal or exceed elevation 1144 a total of 29.3% of the time. Under the future condition, Lake Kemp will exceed elevation 1144 a total of 31.4% to 33.3% of the time, an increase of 2.1 to 4.0%.

Under existing conditions, annual water usage was assumed to be 98,050 acre-feet per year. The selected plan modeling assumptions increased water usage to 159,272 acre-feet per year, an increase of 61,222 acre-feet. As a result of increased water usage, elevations at Lake Kemp will equal or exceed elevation 1144 only 10.7 to 11.4% of the time with the selected plan in operation and 50% brush control at the Truscott gage. This represents a decrease of 18.6 to 17.9% in duration from existing conditions. With the selected plan and 50% basin brush control, Lake Kemp will be at or above elevation 1144 a total of 13.2 to 14.3% of the time, a decrease of 16.1 to 15.0% in duration from existing conditions.

The routing program assumed annual releases for the selected plan would total 159,272 acre-feet per year. Under the selected plan and actual operation of Lake Kemp, this annual total would be viewed as a maximum that would occur only during the driest conditions. The projected elevation duration results listed in Table 18 should be viewed as conservative estimates. Under actual conditions, Lake Kemp elevations are expected to be higher.

Under the Lake Kemp Drought Contingency Plan, the Texas Parks and Wildlife Department's Dundee Fish Hatchery below Lake Diversion will not receive water from Lake Diversion when Lake Kemp is below elevation 1123. Under existing conditions and existing conditions with brush control, the lake is above elevation 1123 almost 100% of the time. Under the selected plan with 50% brush control at Truscott, Lake Kemp is at or above elevation 1123 a total of 83.1 to 83.9% of the time. With brush control implemented in 50% of the basin, Lake Kemp is at or above elevation 1123 a total of 85.2 to 88.3% of the time.

Lake Kemp and Lake Diversion are operated as part of the Wichita County Water Improvement District irrigation system. Lake Kemp provides the storage and yield required for irrigation withdrawals, and Lake Diversion provides the elevation necessary for delivery of water to the canal system. All releases from Lake Kemp travel down the Wichita River to Lake Diversion. During normal operations, the Lake Diversion conservation pool is maintained within 1 to 2 feet of the spillway crest. The spillway crest is at elevation 1052. Floodwater is discharged through the spillway and travels down the Wichita River. Irrigation releases are made through six gates into the irrigation canal.

The outlets to the Dundee Hatchery consist of a 14-inch outlet at elevation 1047 and a 30-inch siphon outlet at elevation 1049. According to the Wichita County Water Improvement District, the 14-inch outlet does not supply enough water so the hatchery depends on the 30-inch outlet. The Water Improvement District must maintain Lake Diversion between elevation 1050 to 1052 year-round to ensure the Dundee Hatchery an uninterrupted water supply. According to Water Improvement District personnel, if Lake Diversion were allowed to lower their elevation during the non-irrigation season, the Lake Kemp/Diversion system could increase their yield by as much as 10,000 acre-feet.

Based on the period of record used in the low flow/concentration duration study, Lake Kemp has an average annual inflow of 177,153 acre-feet per year. Brush control program application for 50% of the Truscott basin is estimated to increase inflows into Lake Kemp by 2.2 to 3.2%. Brush control application for 50% of the basin above Lake Kemp is expected to increase inflows 8.4 to 11.9%. Table 19 presents Lake Kemp inflow data.

**TABLE 19**

**LAKE KEMP AVERAGE ANNUAL INFLOWS**

| | Average Annual Inflow (acre-feet) | Difference From Existing (acre-feet) | Percent Difference From Existing |
|---|---|---|---|
| Existing Conditions | 177,153 | | |
| Selected Plan w/50% Brush Control @ Truscott – 27.6% | 181,051 | 3,874 | 2.2% |
| Selected Plan w/50% Brush Control @ Truscott – 38.9% | 182,822 | 5,669 | 3.2% |
| Selected Plan w/50% Basin Brush Control 27.6% | 192,034 | 14,881 | 8.4% |
| Selected Plan w/50% Basin Brush Control 38.9% | 198,235 | 21,081 | 11.9% |

## CONCLUSIONS

Wichita River chloride control will effectively remove 409 of the total 491 T/D of chloride load from the Wichita River Basin. The selected plan exhibits an effectiveness of 83% for chloride removal and 82% effectiveness for TDS removal. The chloride removal provided by the selected plan is expected to reduce chloride concentrations at Lake Kemp dramatically allowing municipalities and industries reduced treatment costs and increased irrigation production. Under existing conditions, Lake Kemp chloride concentrations are equal to or exceed 1,312 mg/l 50% of the time. Under the selected plan, chloride concentrations are expected to equal or exceed 318 mg/l only 50% of the time. Selected plan chloride concentrations will range between 257 g/l and 318 mg/l between 20 to 50% of the time. The selected plan is expected to meet USEPA secondary drinking water standards for chloride only 10% of the time, but will meet the TNRCC standard for chloride of 300 mg/l 99% of the time.

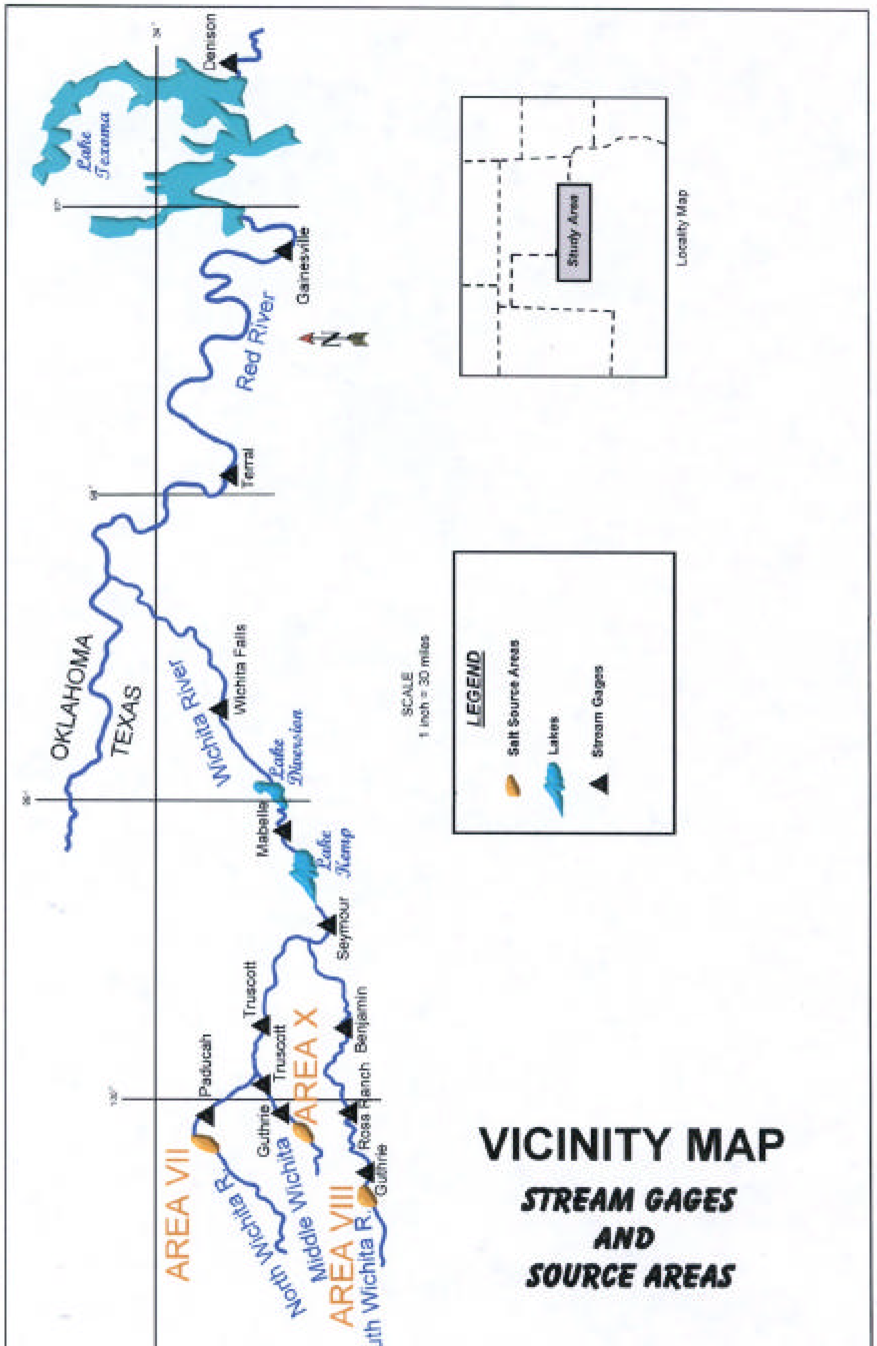
The selected plan will remove an average of 18.6 cfs from existing flows in the upper reaches of the Wichita River Basin. Low flow modeling results indicate that the greatest impact will be experienced on the North and Middle Forks of the Wichita River. The number of zero flow days will increase at the Truscott gage, located below the confluence of the North and Middle Forks, from 2 zero flow days under natural conditions to 1,131 days under the selected plan. This represents an increase of 8.36% based on the number of days in the period of record. Note that the projected 1,131 days occur over a 37-year period of record (13,505 days), an average of 31 zero flow days per year. The application of brush control in 50% of the basin above the Truscott gage and below the collection areas will effectively reduce the number of zero flow days under the selected plan to 614, a decrease of 46%. As a low flow mitigation measure, brush management would significantly reduce the occurrence of low flow days.

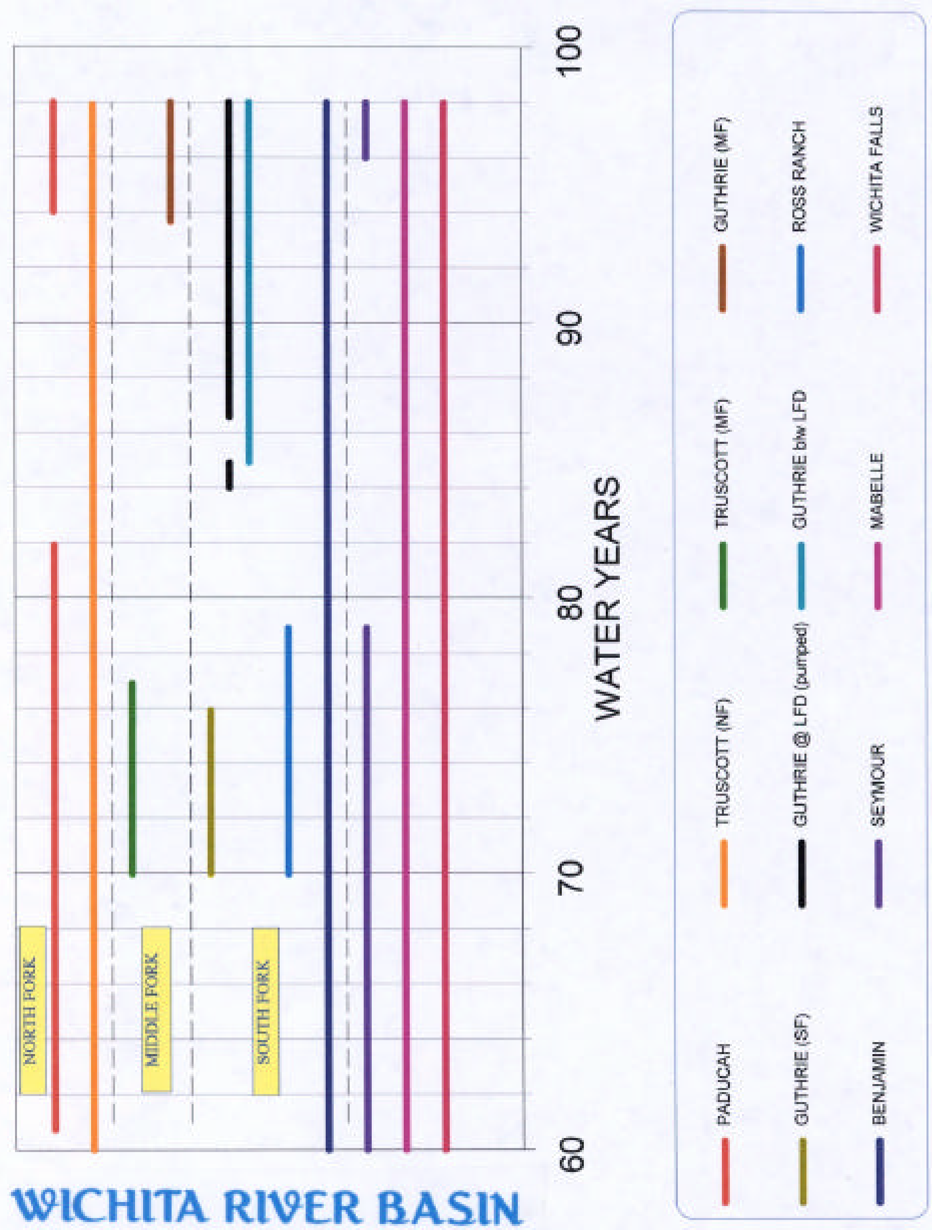
The selected plan is expected to increase water demands on Lake Kemp due to improved water quality. Water usage under the selected plan water use model was increased by 61,222 acre-feet per year for simulation purposes. Elevation duration data indicates that under existing conditions Lake Kemp is at or above elevation 1135 a total of 91.2% of the time. Under the selected plan with brush control implemented at the Truscott gage, Lake Kemp is expected to be at or above elevation 1135 a total of 48.0 – 48.6% of the time. With brush control implemented in 50% of the entire basin, Lake Kemp is expected to be at or above elevation 1135 a total of 51.5 to 53.8% of the time. The increased water demand on Lake Kemp under the selected plan will result in wider fluctuations in elevation. These wider elevation fluctuations should not be interpreted to mean that insufficient storage is available to meet future water demands at Lake Kemp. As the duration data indicates, Lake Kemp will experience lower elevations but will recover as wetter periods are experienced.

# EXHIBITS

**EXHIBIT A**

**FIGURES**


VICINITY MAP
STREAM GAGES
AND
SOURCE AREAS
OKLAHOMA
TEXAS
Lake Texoma
Denison
Gainesville
Red River
Terral
Wichita Falls
Wichita River
Lake Diversion
Mabelle
Lake Kemp
Seymour
Truscott
Truscott
Paducah
Guthrie
Benjamin
Rosa Ranch
Guthrie
AREA VII
AREA X
AREA VIII
North Wichita R.
Middle Wichita
South Wichita R.
SCALE
1 inch = 30 miles
LEGEND
Salt Source Areas
Lakes
Stream Gages
Study Area
Locality Map
FIGURE 1




SUMMARY OF RECORDED FLOW DATA

FIGURE 2

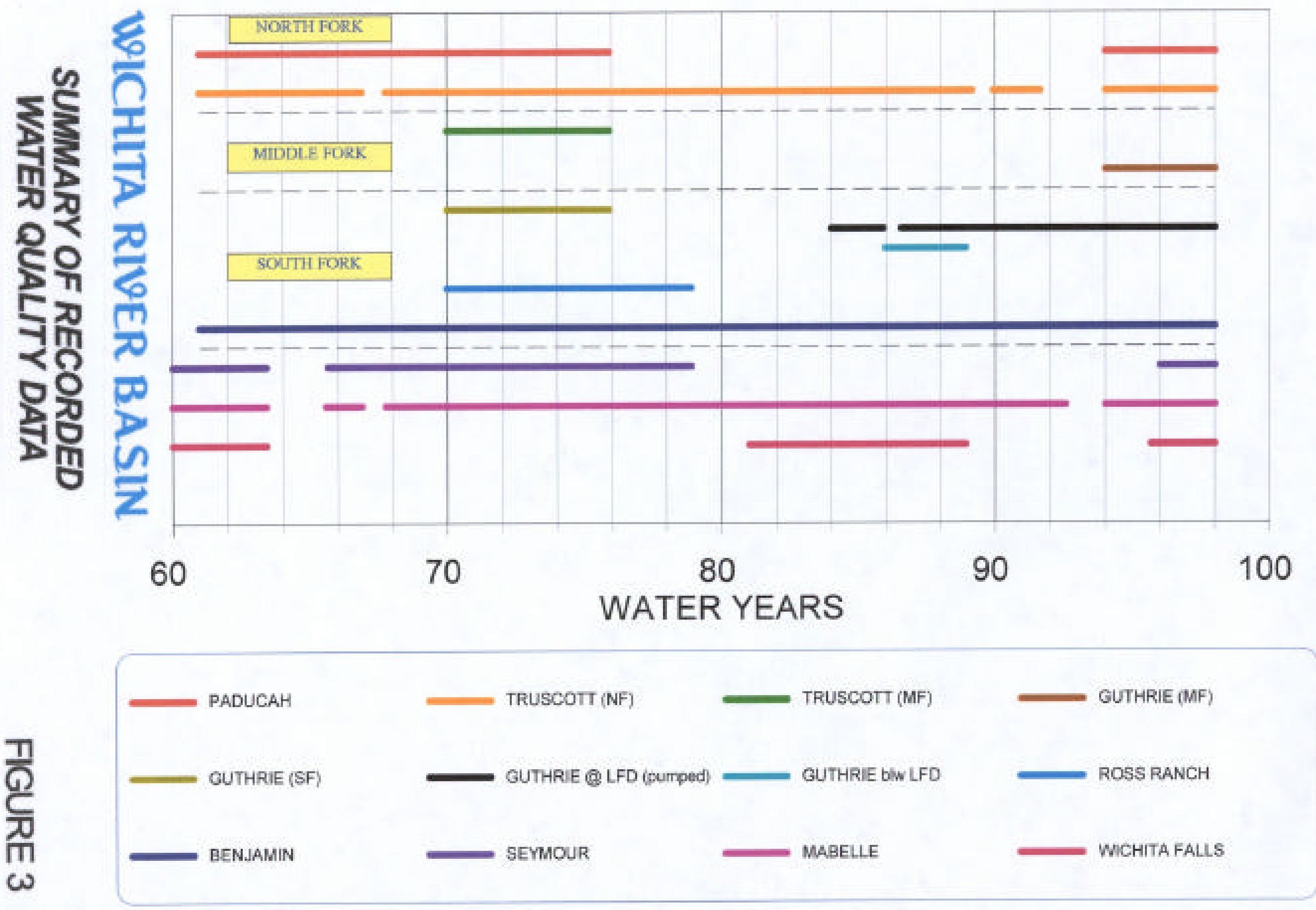
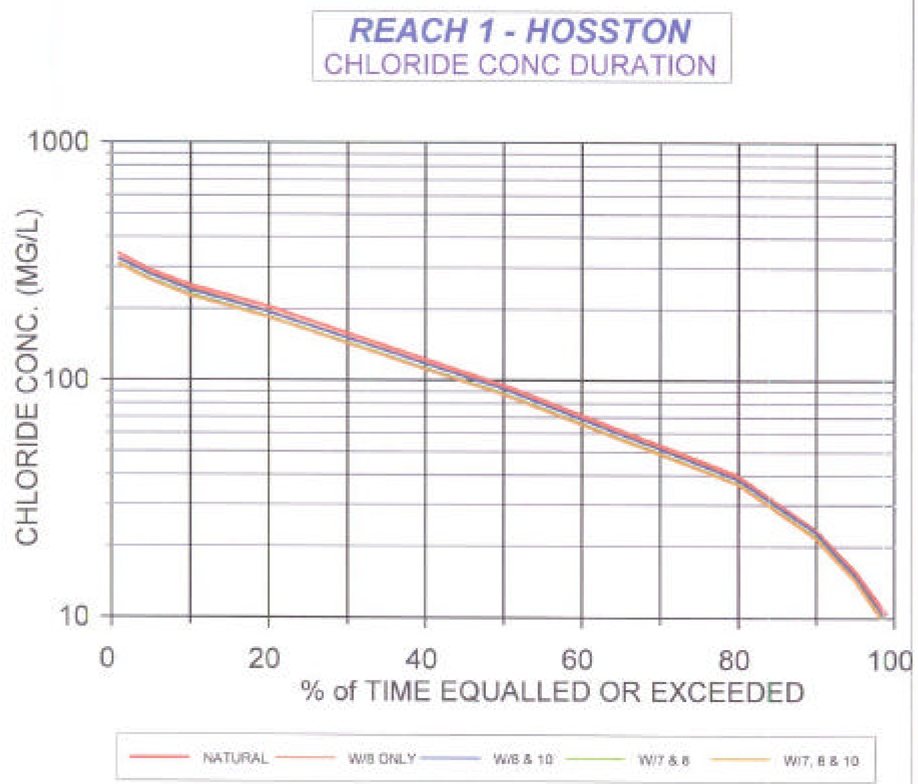

WICHITA RIVER BASIN
SUMMARY OF RECORDED
WATER QUALITY DATA
NORTH FORK
MIDDLE FORK
SOUTH FORK
60
70
80
90
100
WATER YEARS
PADUCAH
TRUSCOTT (NF)
TRUSCOTT (MF)
GUTHRIE (MF)
GUTHRIE (SF)
GUTHRIE @ LFD (pumped)
GUTHRIE blw LFD
ROSS RANCH
BENJAMIN
SEYMOUR
MABELLE
WICHITA FALLS

FIGURE 3

# EXHIBIT B

# CONCENTRATION DURATION PLATES




Based on the period:
Oct 1961 thru Sep 1998

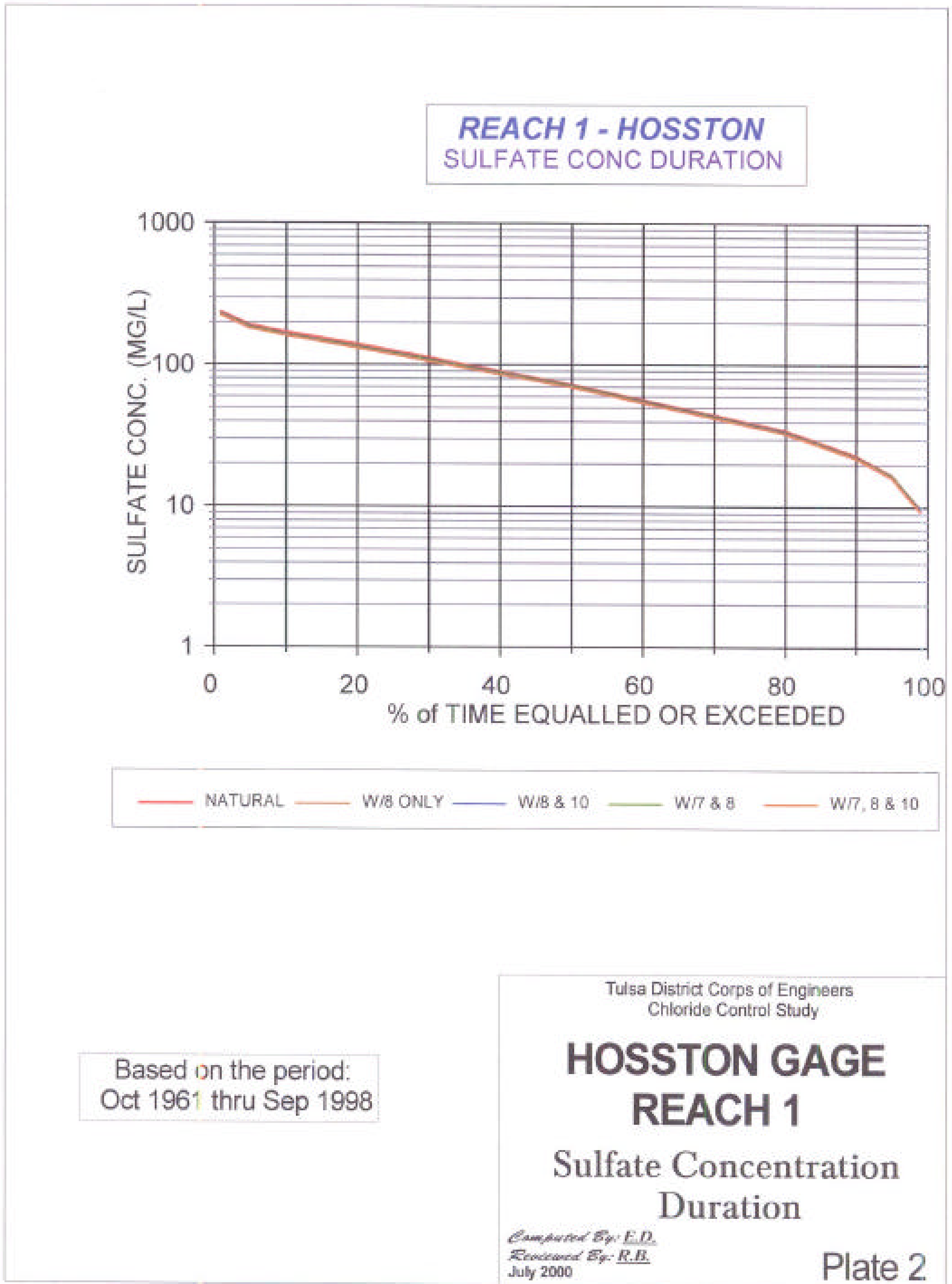
Tulsa District Corps of Engineers
Chloride Control Study

# HOSSTON GAGE
# REACH 1

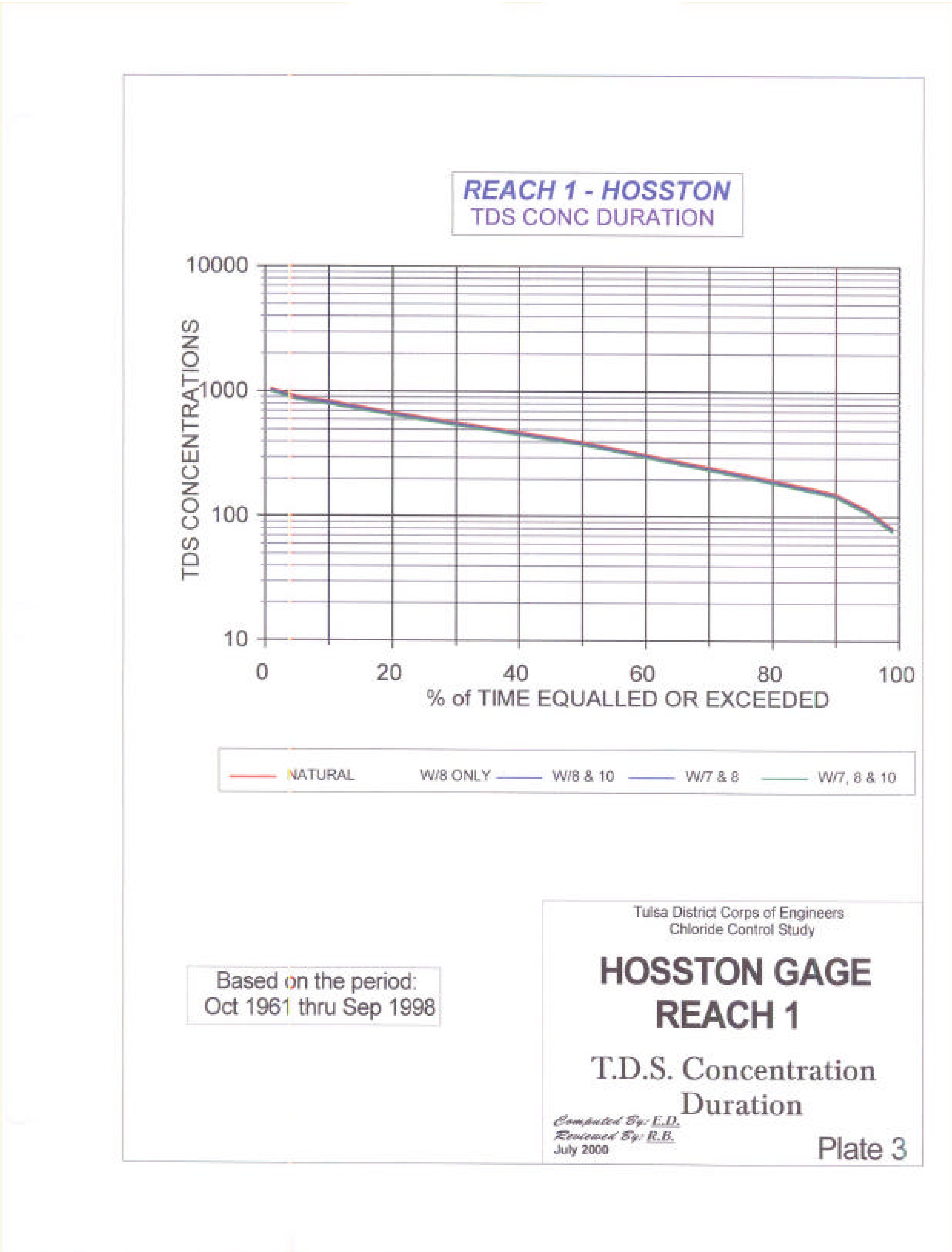
## Chloride Concentration Duration

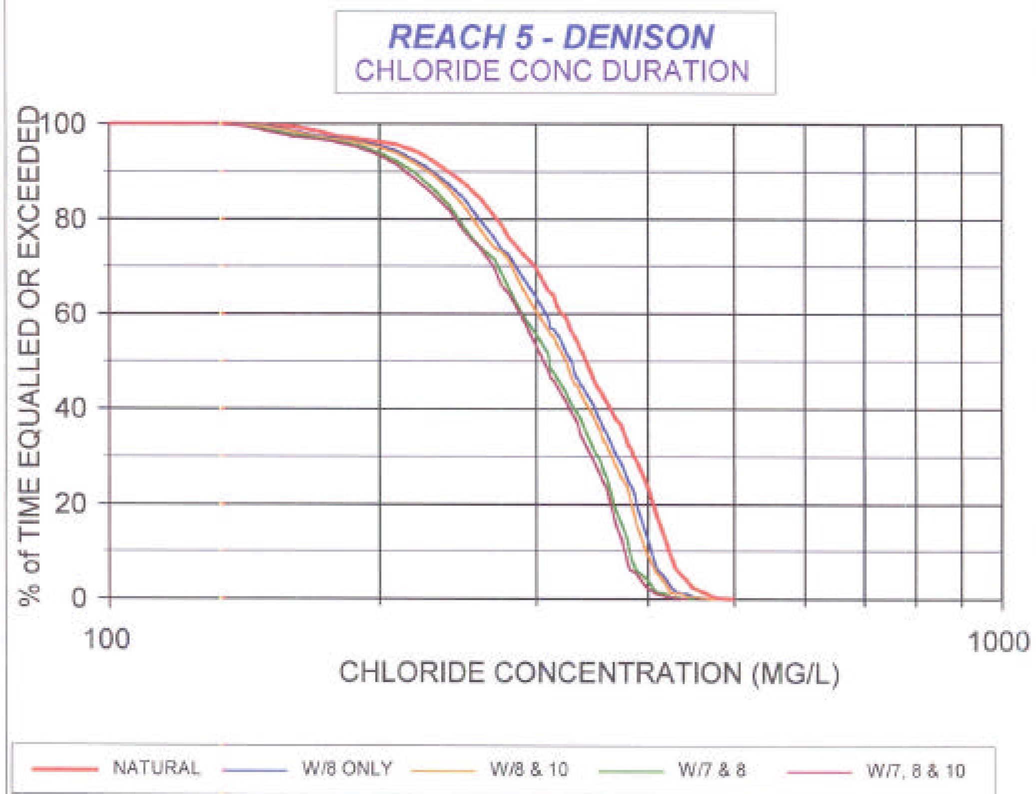
Computed By: E.D.
Reviewed By: R.B.
July 2000

Plate 1



REACH 1 - HOSSTON
SULFATE CONC DURATION
1000
100
10
1
SULFATE CONC. (MG/L)
0
20
40
60
80
100
% of TIME EQUALLED OR EXCEEDED
NATURAL
W/8 ONLY
W/8 & 10
W/7 & 8
W/7, 8 & 10
Based on the period:
Oct 1961 thru Sep 1998
Tulsa District Corps of Engineers
Chloride Control Study
HOSSTON GAGE
REACH 1
Sulfate Concentration
Duration
Computed By: E.D.
Reviewed By: R.B.
July 2000
Plate 2


REACH 1 - HOSSTON
TDS CONC DURATION
10000
1000
100
10
TDS CONCENTRATIONS
0
20
40
60
80
100
% of TIME EQUALLED OR EXCEEDED
NATURAL
W/8 ONLY
W/8 & 10
W/7 & 8
W/7, 8 & 10
Based on the period:
Oct 1961 thru Sep 1998
Tulsa District Corps of Engineers
Chloride Control Study
HOSSTON GAGE
REACH 1
T.D.S. Concentration
Duration
Computed By: E.D.
Reviewed By: R.B.
July 2000
Plate 3




Based on the period:
Oct 1961 thru Sep 1998

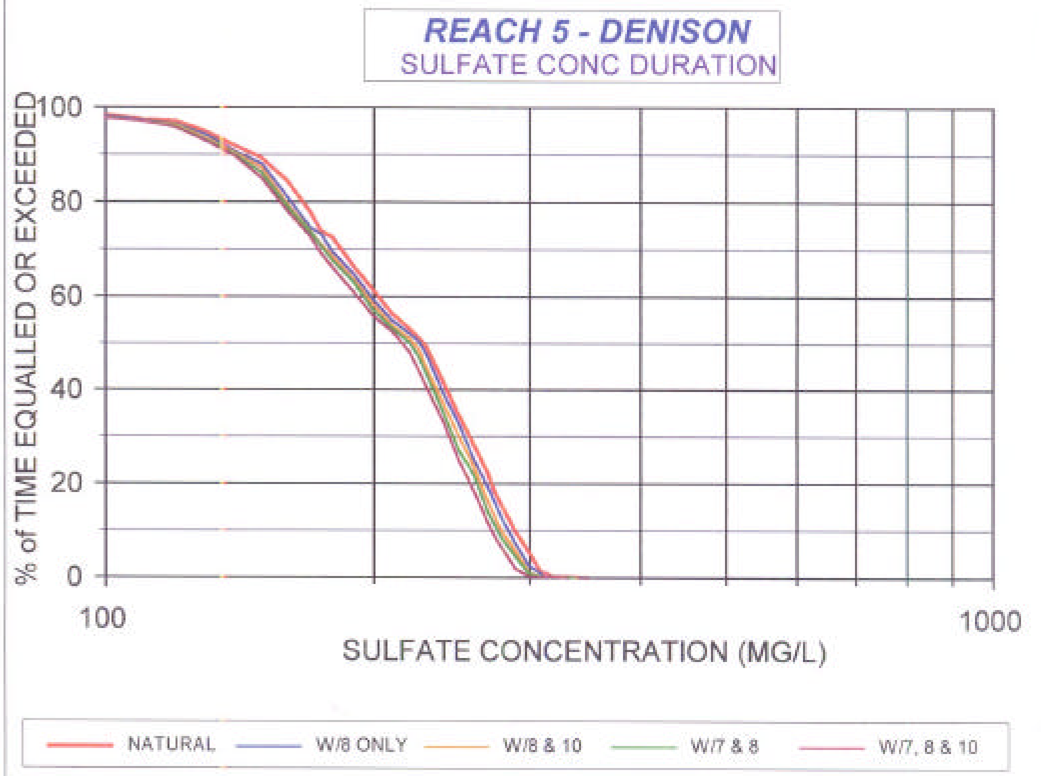
Tulsa District Corps of Engineers
Chloride Control Study

# DENISON GAGE
# REACH 5

## Chloride Concentration Duration

*Computed By:* E.D.
*Reviewed By:* R.B.
July 2000

Plate 4




Based on the period:
Oct 1961 thru Sep 1998

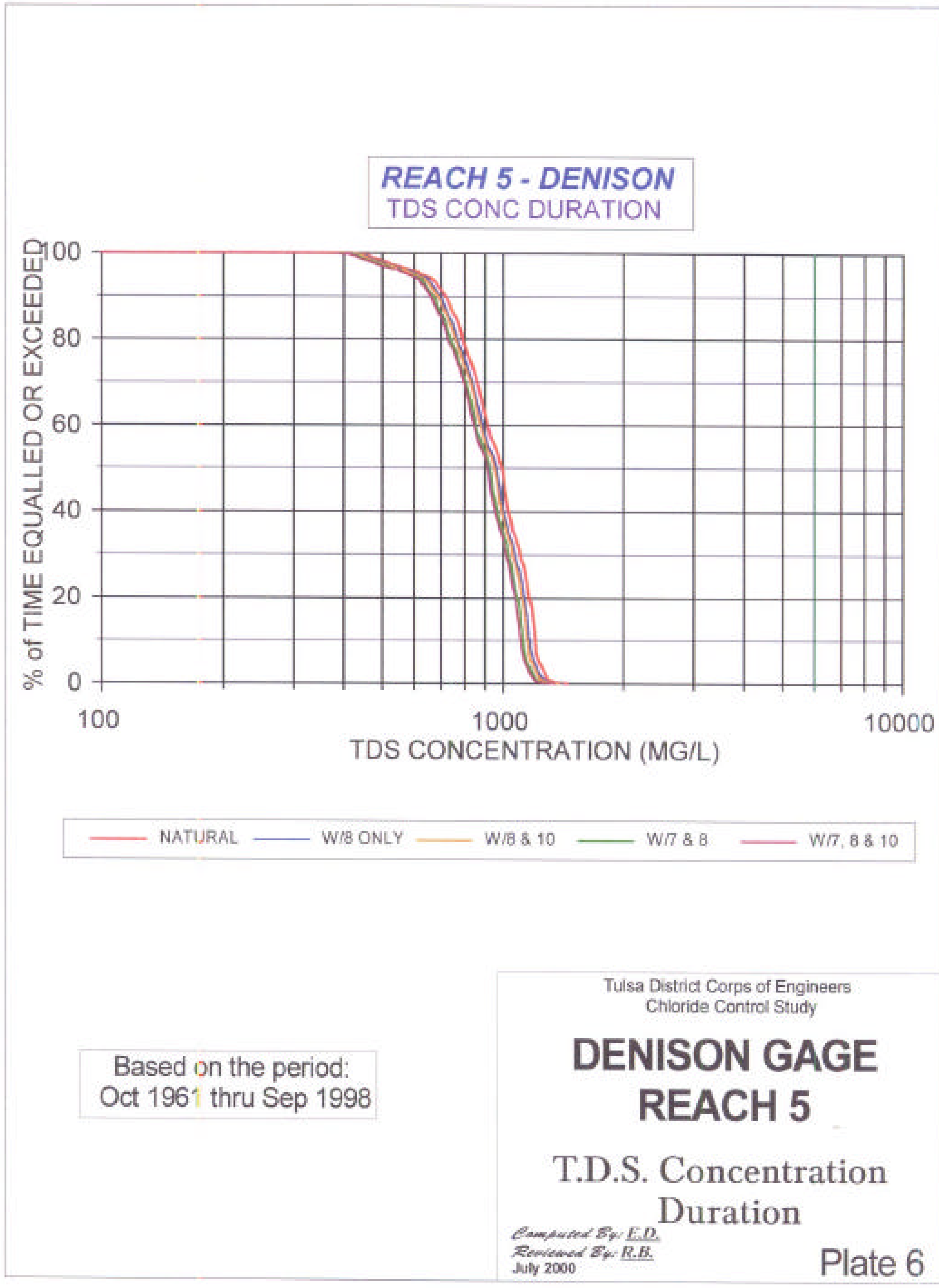
Tulsa District Corps of Engineers
Chloride Control Study

# DENISON GAGE
# REACH 5

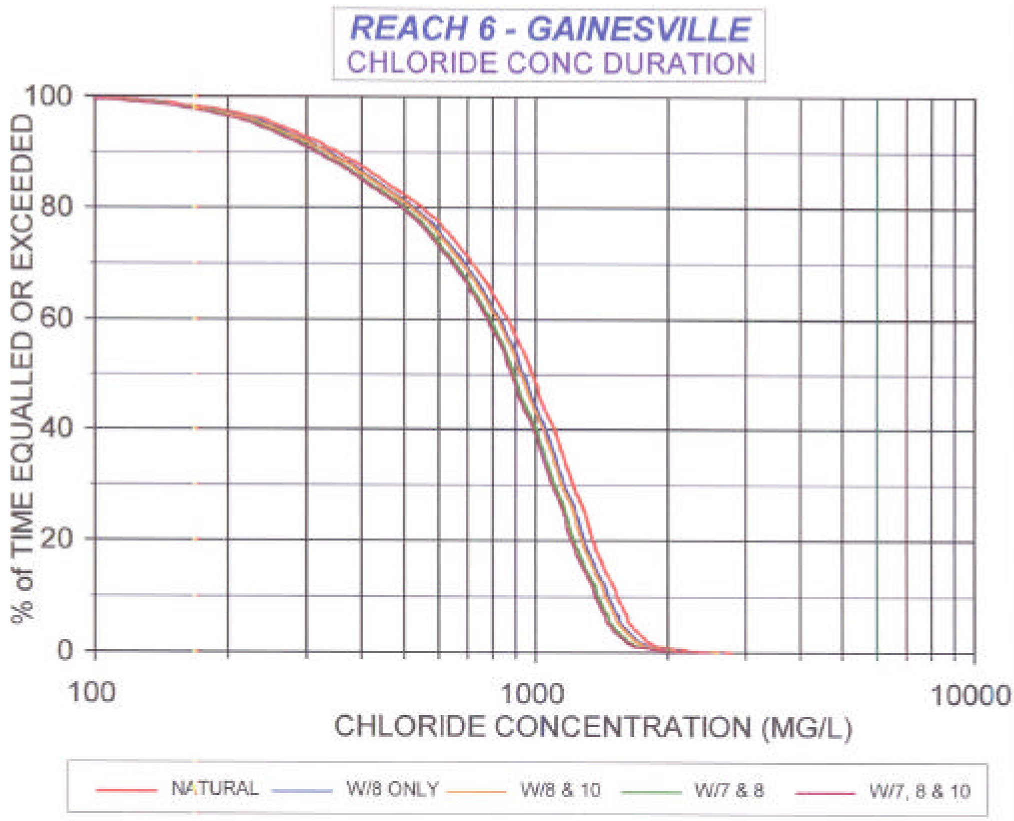
## Sulfate Concentration Duration

Computed By: E.D.
Reviewed By: R.B.
July 2000

Plate 5



REACH 5 - DENISON
TDS CONC DURATION
% of TIME EQUALLED OR EXCEEDED
100
80
60
40
20
0
100
1000
10000
TDS CONCENTRATION (MG/L)
NATURAL
W/8 ONLY
W/8 & 10
W/7 & 8
W/7, 8 & 10
Based on the period:
Oct 1961 thru Sep 1998
Tulsa District Corps of Engineers
Chloride Control Study
DENISON GAGE
REACH 5
T.D.S. Concentration
Duration
Computed By: E.D.
Reviewed By: R.B.
July 2000
Plate 6




Based on the period:
Oct 1961 thru Sep 1998

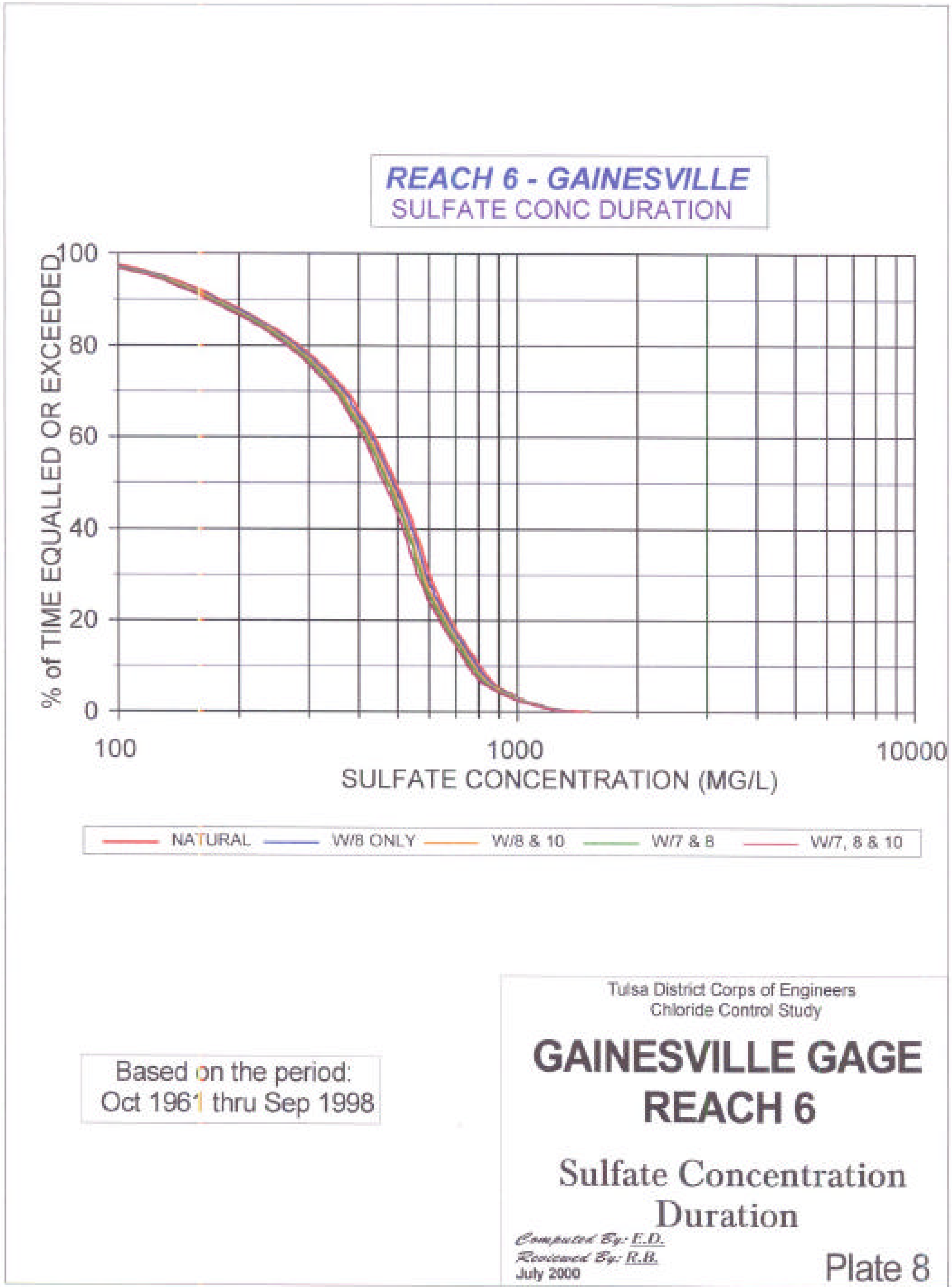
Tulsa District Corps of Engineers
Chloride Control Study

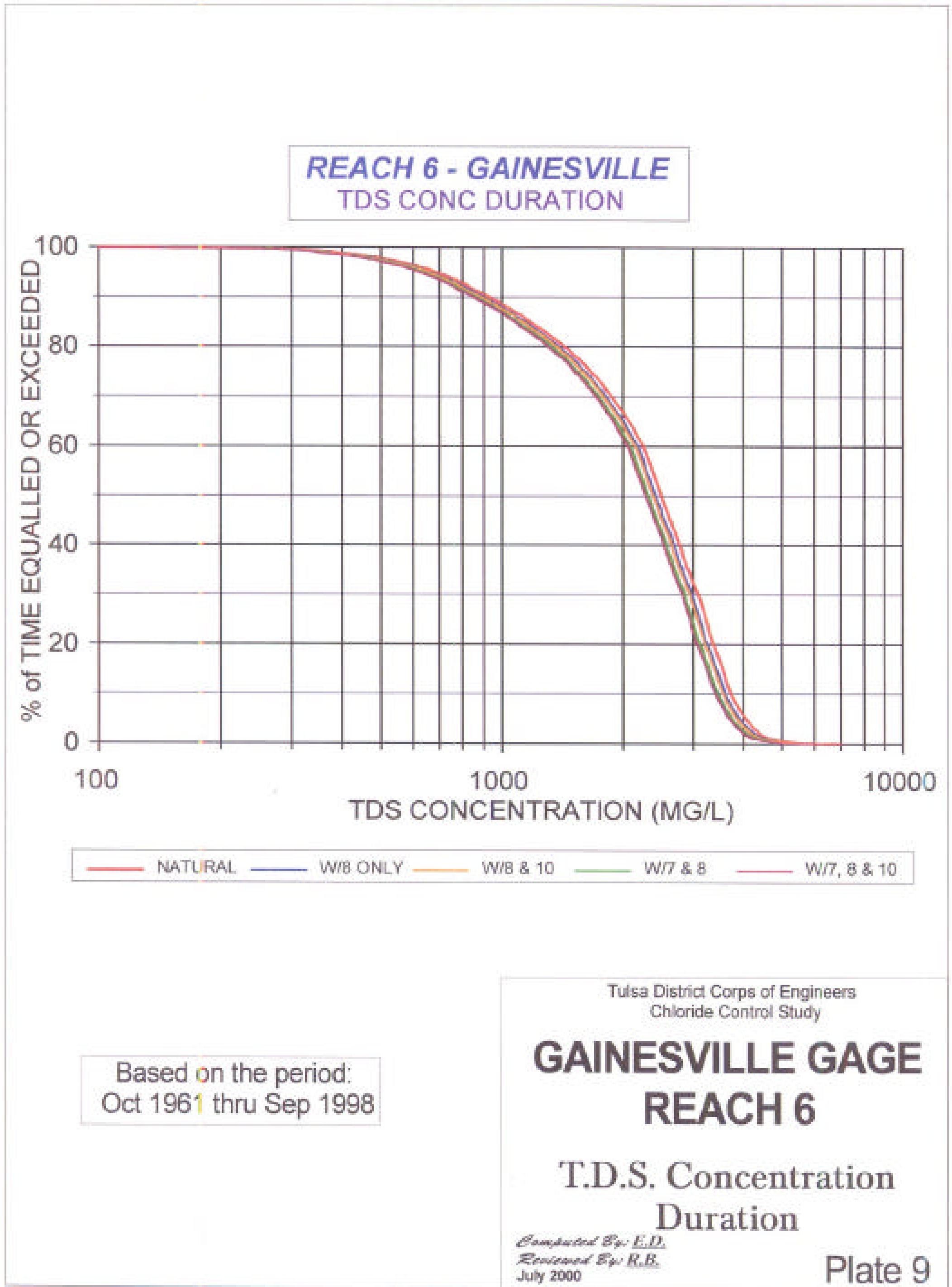
# GAINESVILLE GAGE
# REACH 6

## Chloride Concentration Duration

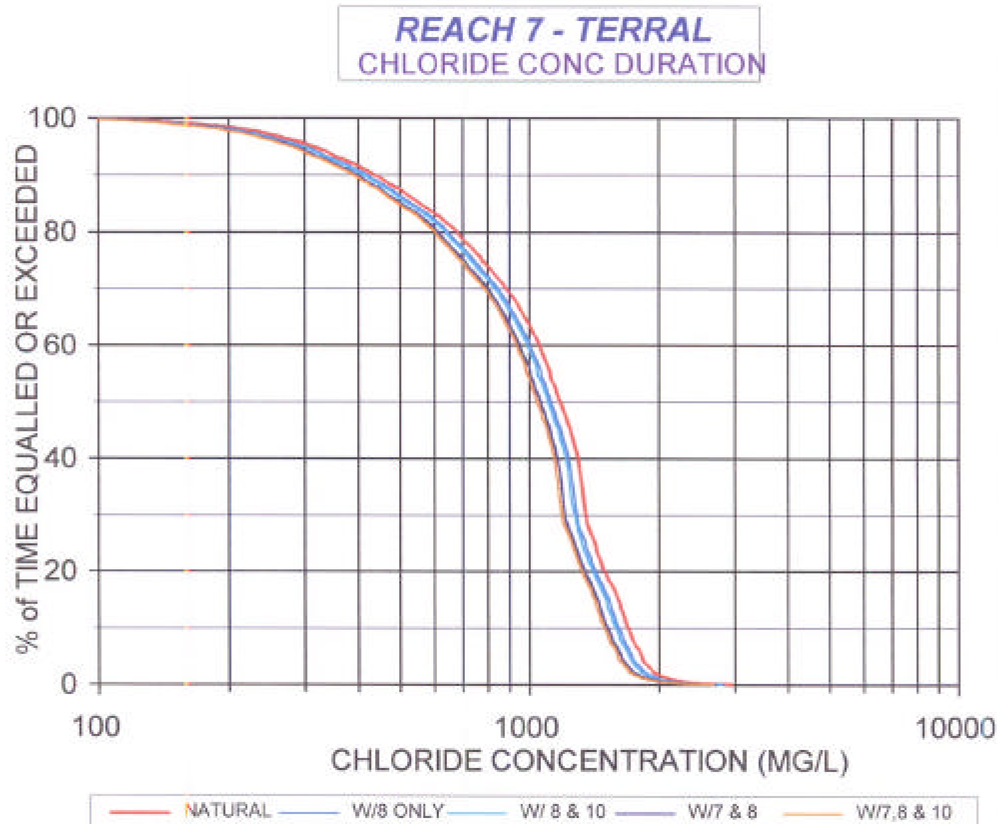
*Computed By:* E.D.
*Reviewed By:* R.B.
July 2000

Plate 7


REACH 6 - GAINESVILLE
SULFATE CONC DURATION
% of TIME EQUALLED OR EXCEEDED
100
80
60
40
20
0
100
1000
10000
SULFATE CONCENTRATION (MG/L)
NATURAL
W/8 ONLY
W/8 & 10
W/7 & 8
W/7, 8 & 10
Based on the period:
Oct 1961 thru Sep 1998
Tulsa District Corps of Engineers
Chloride Control Study
GAINESVILLE GAGE
REACH 6
Sulfate Concentration
Duration
Computed By: E.D.
Reviewed By: R.B.
July 2000
Plate 8



REACH 6 - GAINESVILLE
TDS CONC DURATION
% of TIME EQUALLED OR EXCEEDED
100
80
60
40
20
0
100
1000
10000
TDS CONCENTRATION (MG/L)
NATURAL
W/8 ONLY
W/8 & 10
W/7 & 8
W/7, 8 & 10
Based on the period:
Oct 1961 thru Sep 1998
Tulsa District Corps of Engineers
Chloride Control Study
GAINESVILLE GAGE
REACH 6
T.D.S. Concentration
Duration
Computed By: E.D.
Reviewed By: R.B.
July 2000
Plate 9




Based on the period:
Oct 1961 thru Sep 1998

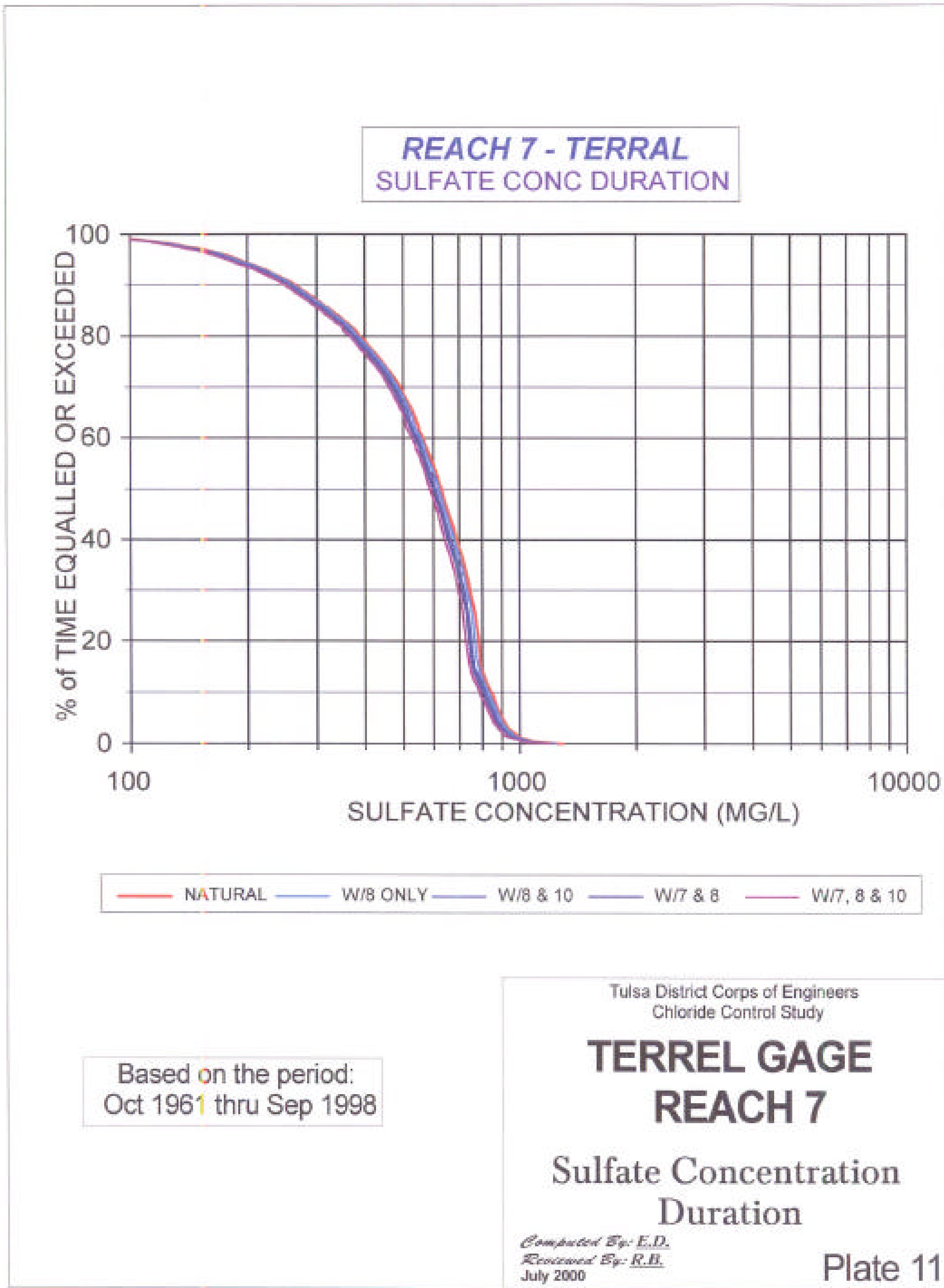
Tulsa District Corps of Engineers
Chloride Control Study

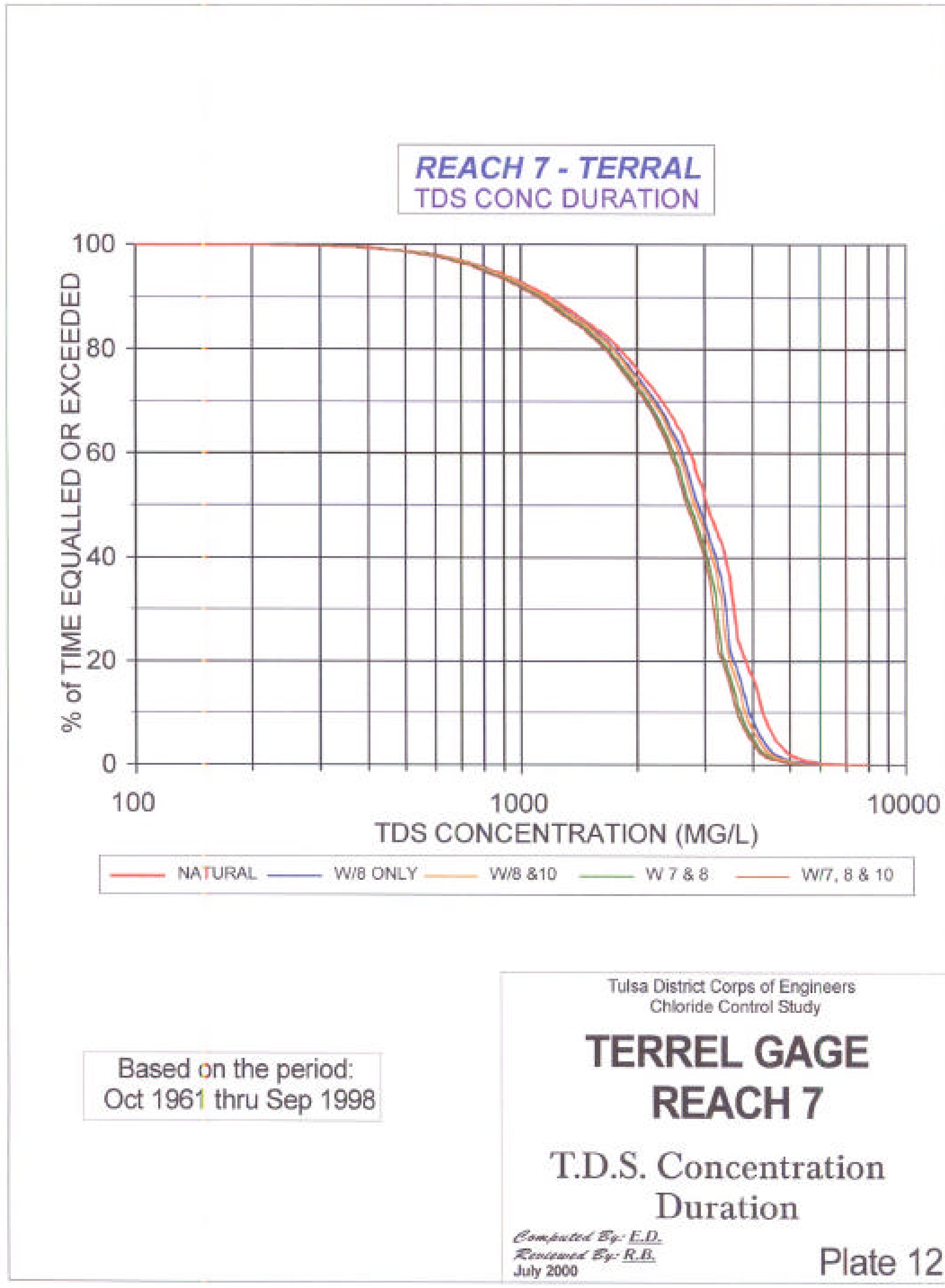
**TERREL GAGE**
**REACH 7**

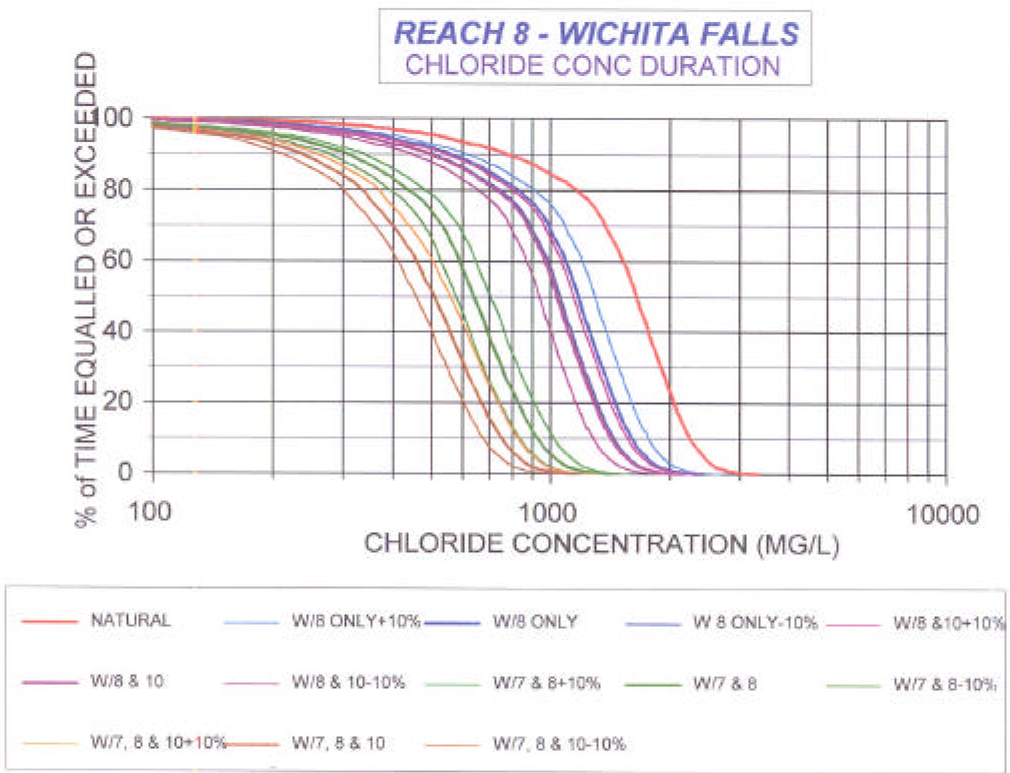
Chloride Concentration
Duration

*Computed By: E.D.*
*Reviewed By: R.B.*
July 2000

Plate 10


REACH 7 - TERRAL
SULFATE CONC DURATION
% of TIME EQUALLED OR EXCEEDED
100
80
60
40
20
0
100
1000
10000
SULFATE CONCENTRATION (MG/L)
NATURAL
W/8 ONLY
W/8 & 10
W/7 & 8
W/7, 8 & 10
Based on the period:
Oct 1961 thru Sep 1998
Tulsa District Corps of Engineers
Chloride Control Study
TERREL GAGE
REACH 7
Sulfate Concentration
Duration
Computed By: E.D.
Reviewed By: R.B.
July 2000
Plate 11


REACH 7 - TERRAL
TDS CONC DURATION
% of TIME EQUALLED OR EXCEEDED
100
80
60
40
20
0
100
1000
10000
TDS CONCENTRATION (MG/L)
NATURAL
W/8 ONLY
W/8 &10
W 7 & 8
W/7, 8 & 10
Based on the period:
Oct 1961 thru Sep 1998
Tulsa District Corps of Engineers
Chloride Control Study
TERREL GAGE
REACH 7
T.D.S. Concentration
Duration
Computed By: E.D.
Reviewed By: R.B.
July 2000
Plate 12




Based on the period:
Oct 1961 thru Sep 1998

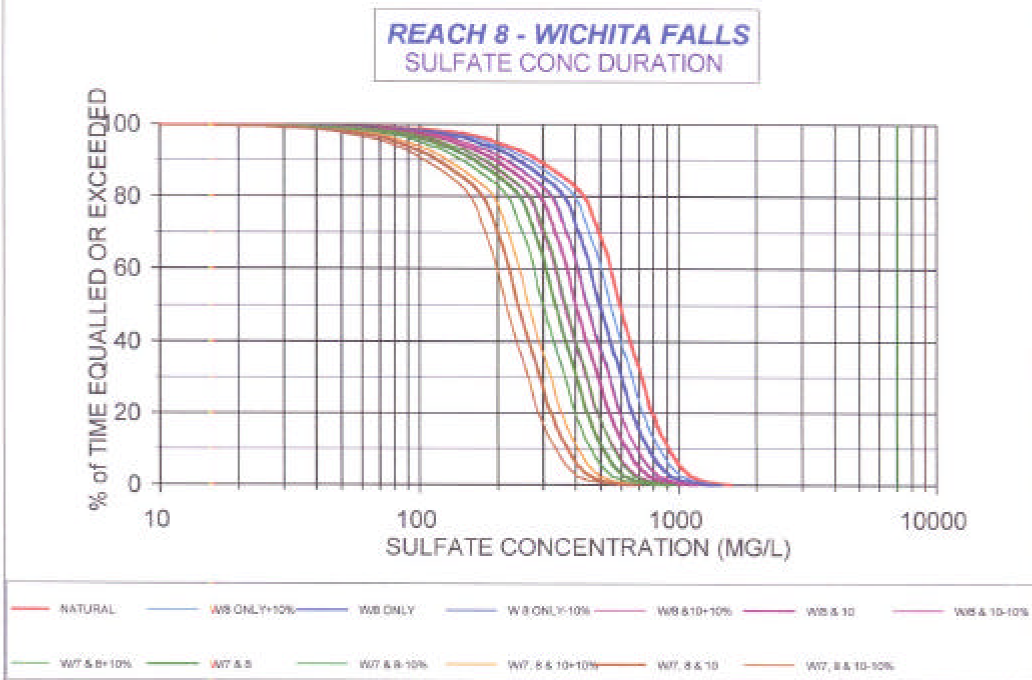
Tulsa District Corps of Engineers
Chloride Control Study

# WICHITA FALLS GAGE
# REACH 8

## Chloride Concentration Duration

*Computed By:* E.D.
*Reviewed By:* R.B.
July 2000

Plate 13




Based on the period:
Oct 1961 thru Sep 1998

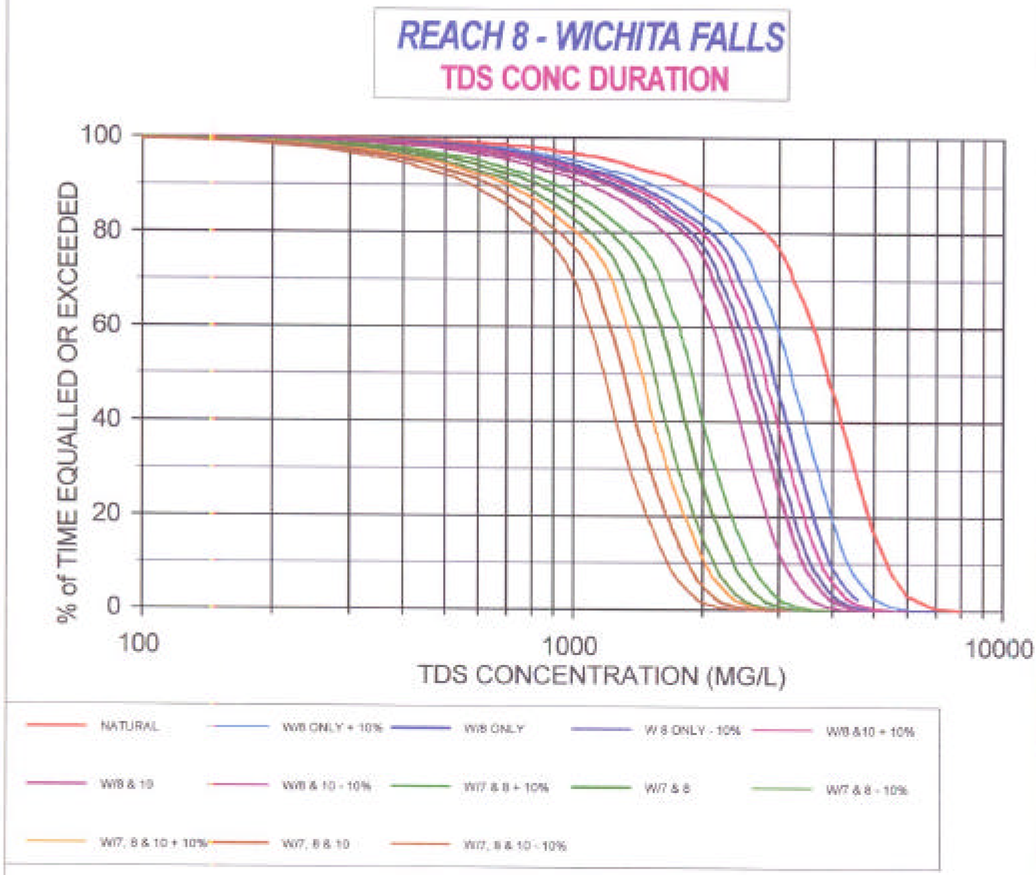
Tulsa District Corps of Engineers
Chloride Control Study

# WICHITA FALLS GAGE
# REACH 8

## Sulfate Concentration Duration

Computed By: E.D.
Reviewed By: R.B.
July 2000

Plate 14




Based on the period:
Oct 1961 thru Sep 1998

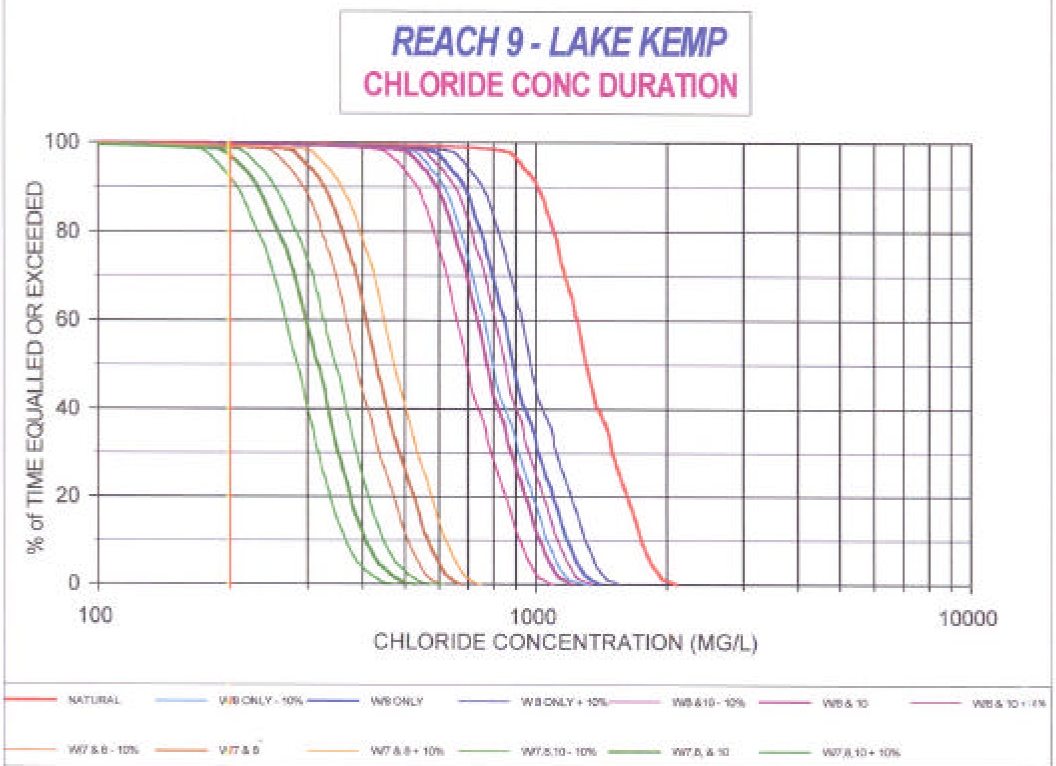
Tulsa District Corps of Engineers
Chloride Control Study

**WICHITA FALLS GAGE**
**REACH 8**

T.D.S. Concentration
Duration

*Computed By:* E.D.
*Reviewed By:* R.B.
July 2000

Plate 15




Based on the period:
Oct 1961 thru Sep 1998

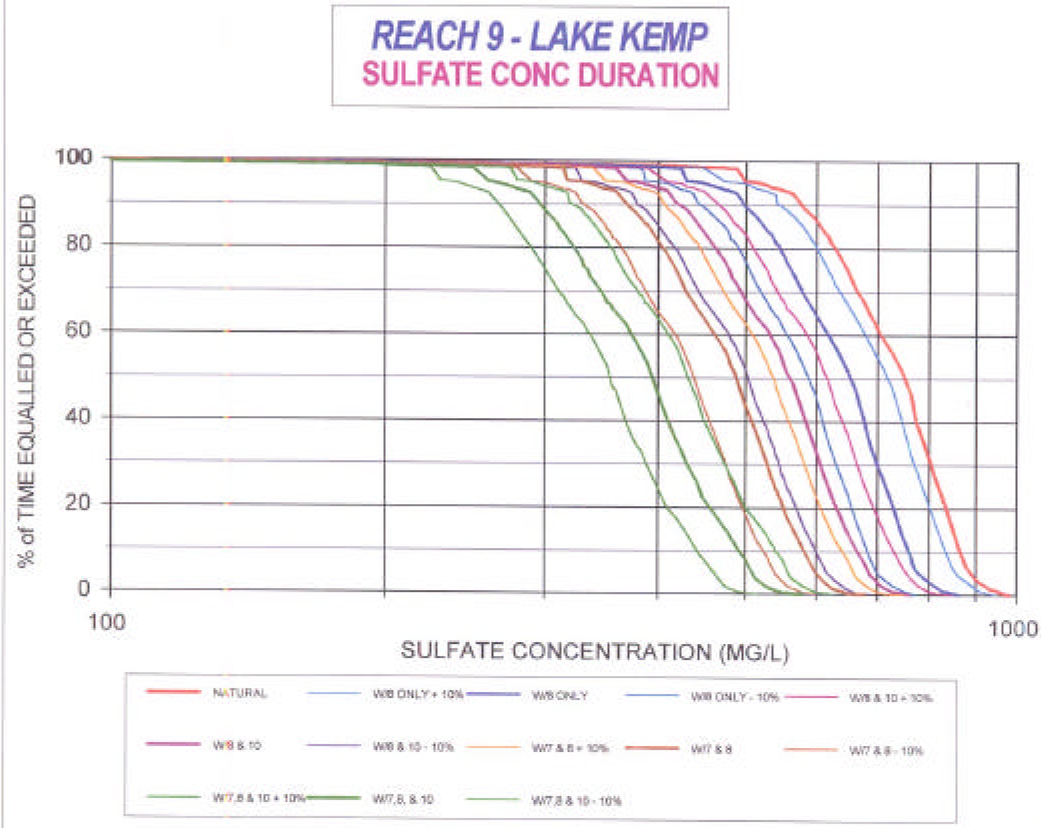
Tulsa District Corps of Engineers
Chloride Control Study

# LAKE KEMP-MABELLE
# REACH 9

## Chloride Concentration Duration

Computed By: E.D.
Reviewed By: R.B.
July 2000

Plate 16




Based on the period:
Oct 1961 thru Sep 1998

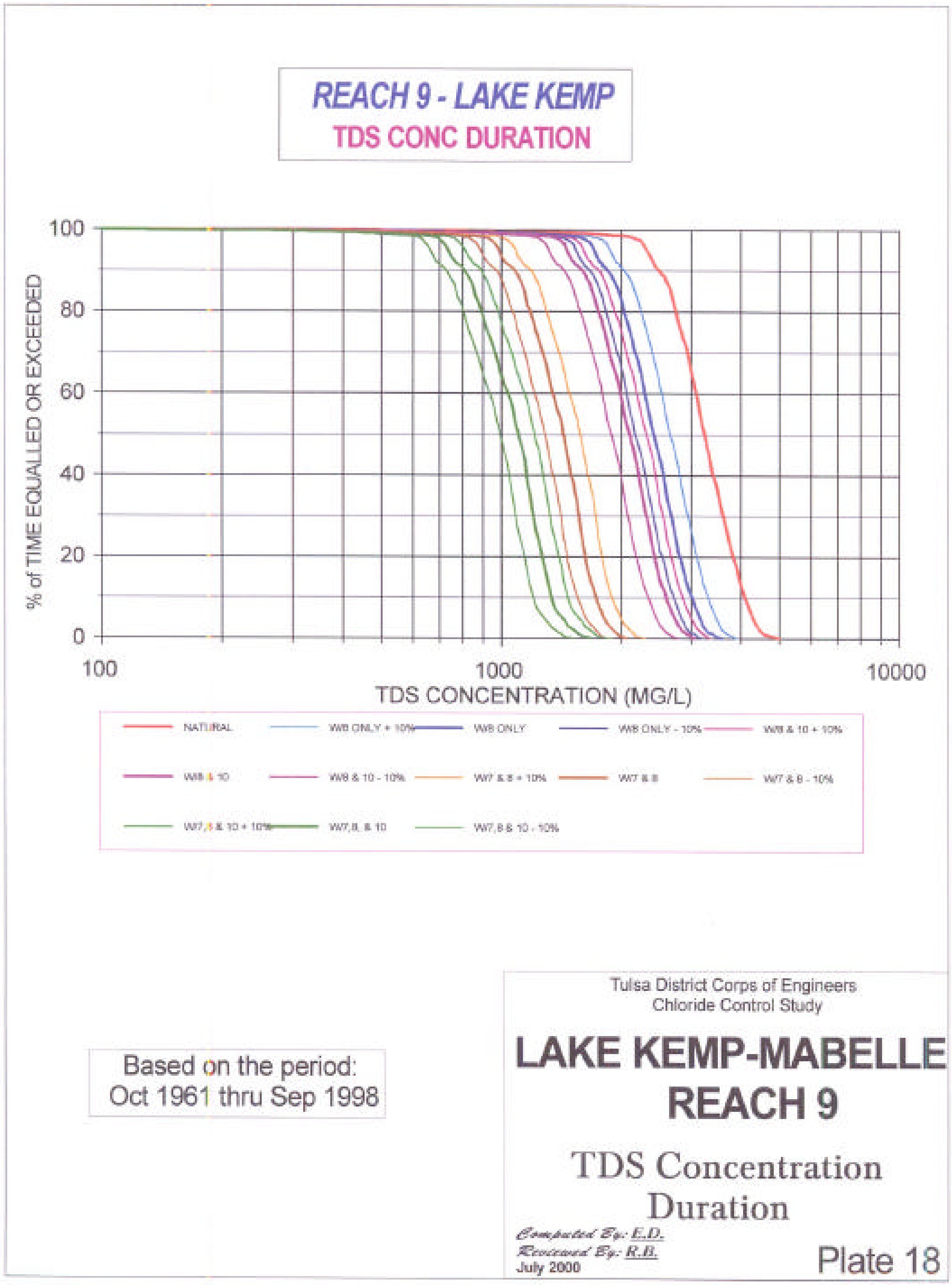
Tulsa District Corps of Engineers
Chloride Control Study

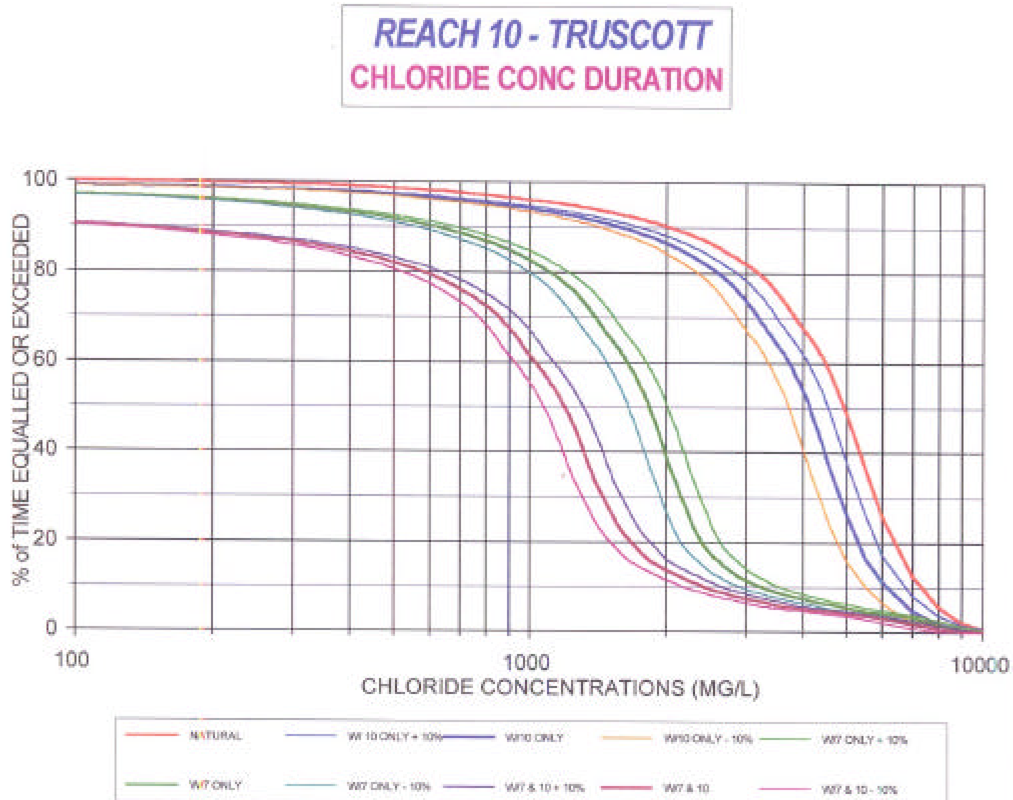
# LAKE KEMP-MABELLE
# REACH 9

## Sulfate Concentration Duration

*Computed By:* E.D.
*Reviewed By:* R.B.
July 2000

Plate 17


REACH 9 - LAKE KEMP
TDS CONC DURATION
% of TIME EQUALLED OR EXCEEDED
100
80
60
40
20
0
100
1000
10000
TDS CONCENTRATION (MG/L)
NATURAL
W8 ONLY + 10%
W8 ONLY
W8 ONLY - 10%
W8 & 10 + 10%
W8 & 10
W8 & 10 - 10%
W7 & 8 + 10%
W7 & 8
W7 & 8 - 10%
W7,8 & 10 + 10%
W7,8, & 10
W7,8 & 10 - 10%
Based on the period:
Oct 1961 thru Sep 1998
Tulsa District Corps of Engineers
Chloride Control Study
LAKE KEMP-MABELLE
REACH 9
TDS Concentration
Duration
Computed By: E.D.
Reviewed By: R.B.
July 2000
Plate 18




Based on the period:
Oct 1961 thru Sep 1998

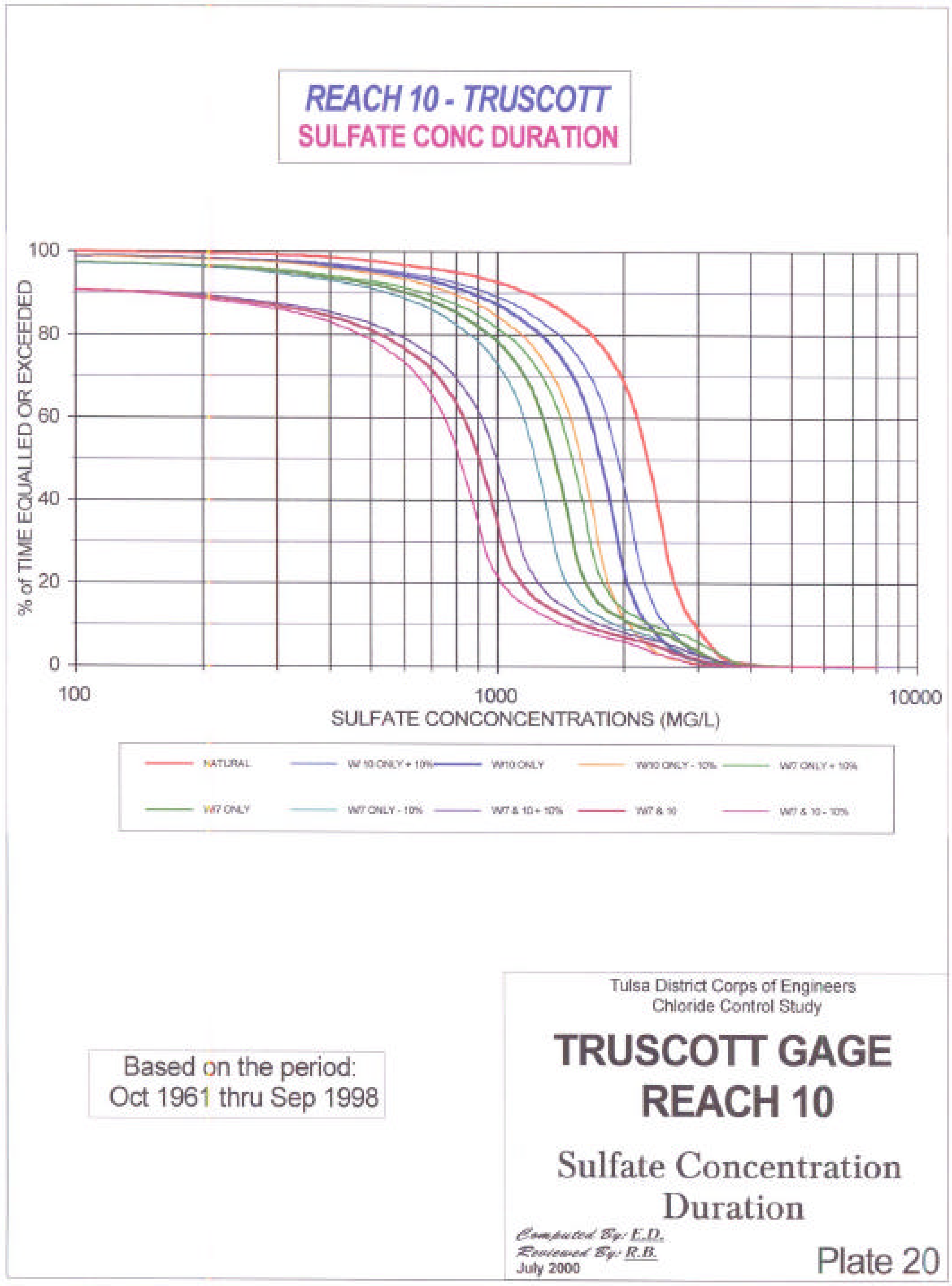
Tulsa District Corps of Engineers
Chloride Control Study

**TRUSCOTT GAGE**
**REACH 10**

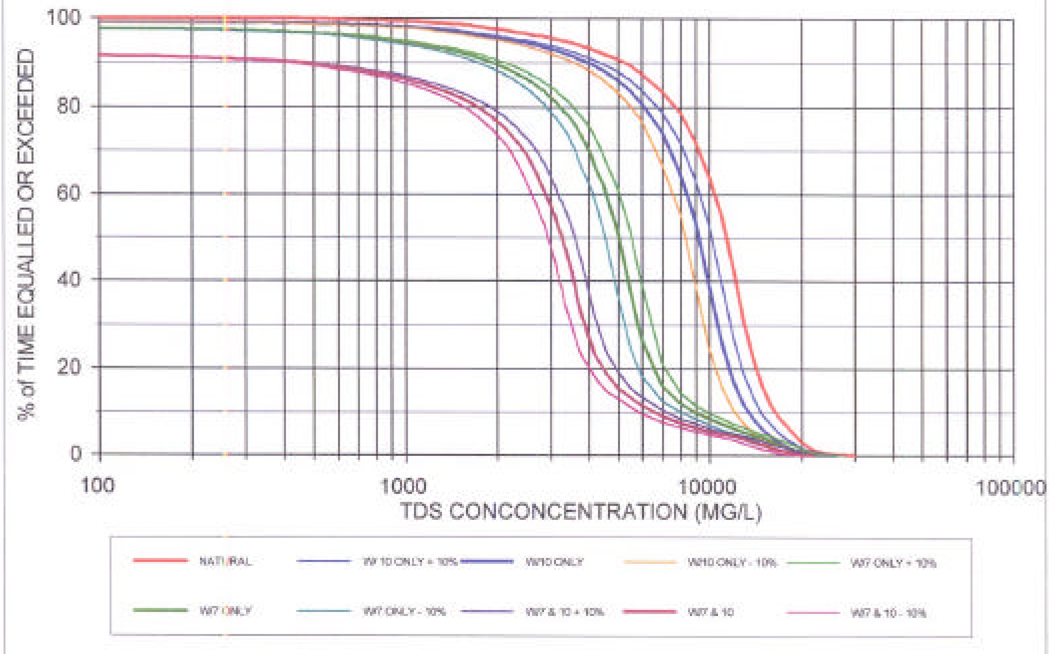
Chloride Concentration
Duration

*Computed By: E.D.*
*Reviewed By: R.B.*
July 2000

Plate 19


REACH 10 - TRUSCOTT
SULFATE CONC DURATION
100
80
60
40
20
0
% of TIME EQUALLED OR EXCEEDED
100
1000
10000
SULFATE CONCONCENTRATIONS (MG/L)
NATURAL
W 10 ONLY + 10%
W10 ONLY
W10 ONLY - 10%
W7 ONLY + 10%
W7 ONLY
W7 ONLY - 10%
W7 & 10 + 10%
W7 & 10
W7 & 10 - 10%
Based on the period:
Oct 1961 thru Sep 1998
Tulsa District Corps of Engineers
Chloride Control Study
TRUSCOTT GAGE
REACH 10
Sulfate Concentration
Duration
Computed By: E.D.
Reviewed By: R.B.
July 2000
Plate 20

**REACH 10 - TRUSCOTT**
**TDS CONC DURATION**




Based on the period:
Oct 1961 thru Sep 1998

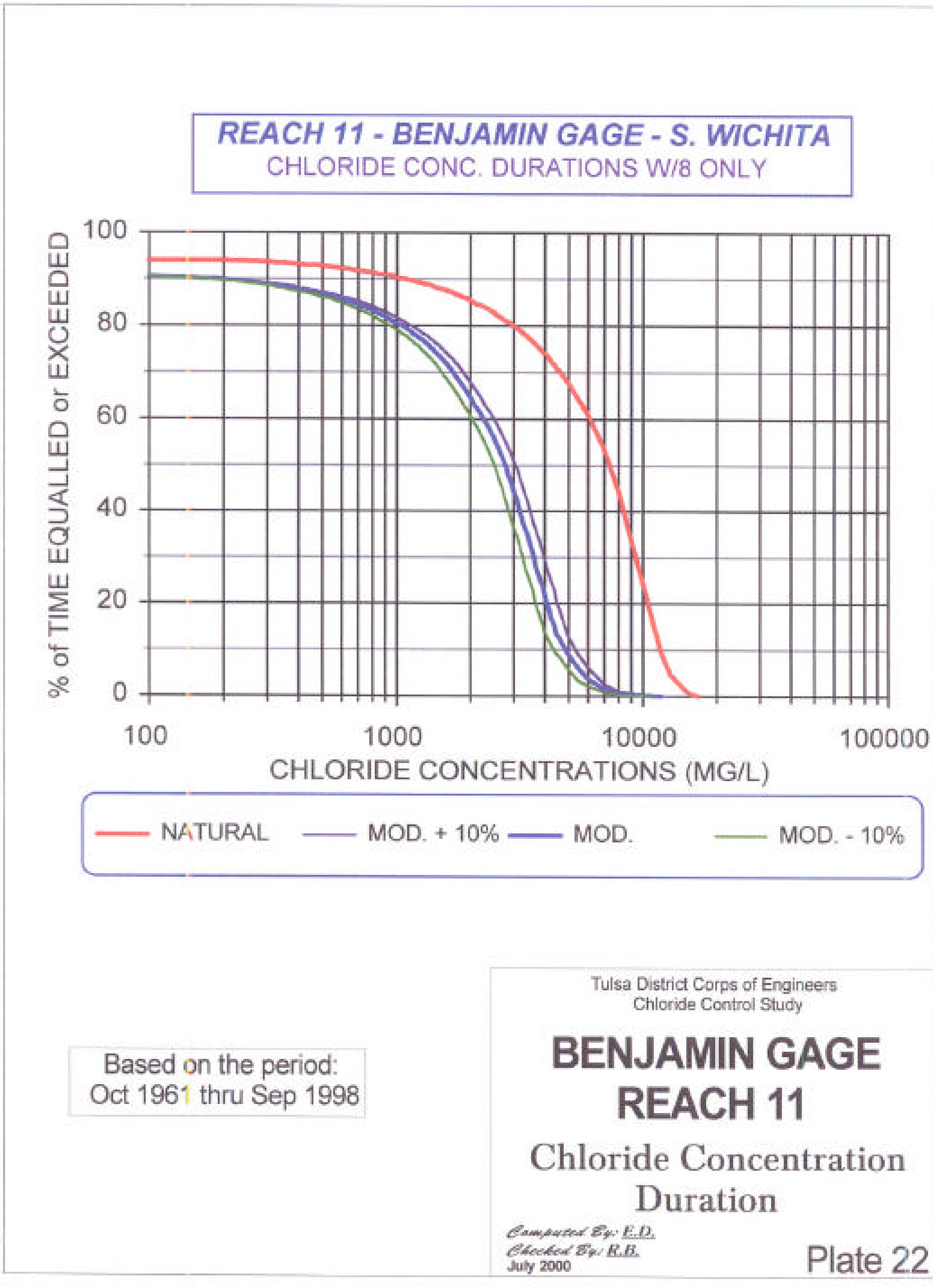
Tulsa District Corps of Engineers
Chloride Control Study

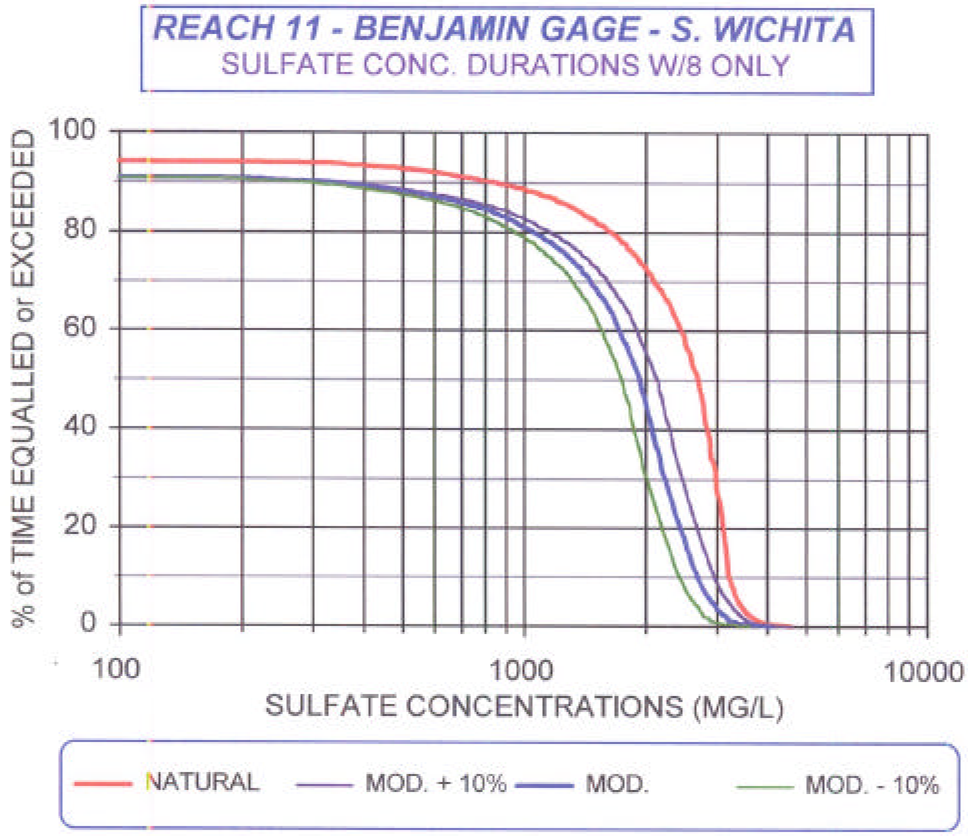
**TRUSCOTT GAGE**
**REACH 10**

TDS Concentration Duration

*Computed By:* E.D.
*Reviewed By:* R.B.
July 2000

Plate 21


REACH 11 - BENJAMIN GAGE - S. WICHITA
CHLORIDE CONC. DURATIONS W/8 ONLY
% of TIME EQUALLED or EXCEEDED
100
80
60
40
20
0
100
1000
10000
100000
CHLORIDE CONCENTRATIONS (MG/L)
NATURAL
MOD. + 10%
MOD.
MOD. - 10%
Based on the period:
Oct 1961 thru Sep 1998
Tulsa District Corps of Engineers
Chloride Control Study
BENJAMIN GAGE
REACH 11
Chloride Concentration
Duration
Computed By: E.D.
Checked By: R.B.
July 2000
Plate 22




Based on the period:
Oct 1961 thru Sep 1998

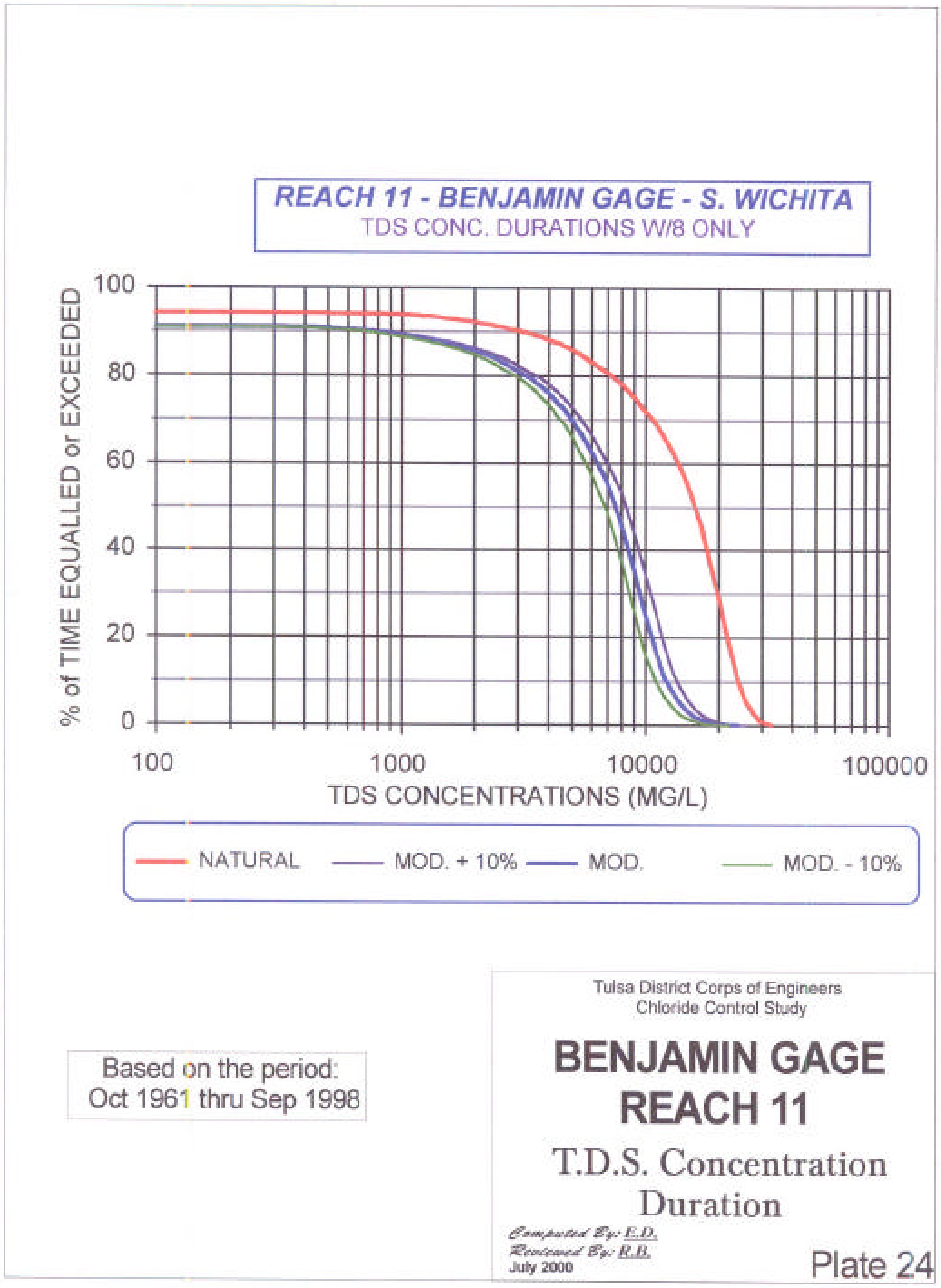
Tulsa District Corps of Engineers
Chloride Control Study

**BENJAMIN GAGE**
**REACH 11**

Sulfate Concentration
Duration

Computed By: E.D.
Reviewed By: R.B.
July 2000

Plate 23


REACH 11 - BENJAMIN GAGE - S. WICHITA
TDS CONC. DURATIONS W/8 ONLY
% of TIME EQUALLED or EXCEEDED
100
80
60
40
20
0
100
1000
10000
100000
TDS CONCENTRATIONS (MG/L)
NATURAL
MOD. + 10%
MOD.
MOD. - 10%
Based on the period:
Oct 1961 thru Sep 1998
Tulsa District Corps of Engineers
Chloride Control Study
BENJAMIN GAGE
REACH 11
T.D.S. Concentration
Duration
Computed By: E.D.
Reviewed By: R.B.
July 2000
Plate 24

## EXHIBIT C

## CONCENTRATION DURATION TABLES

## TABLE 1

## HOSSTON DURATION TABLE
## HYDROLOGIC REACH 1 - RED RIVER

| | NATURAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 342 | 291 | 253 | 205 | 96 | 40 | 24 | 16 | 11 |
| Sulfates | 236 | 191 | 169 | 139 | 72 | 35 | 23 | 17 | 10 |
| TDS | 1054 | 908 | 841 | 680 | 398 | 198 | 153 | 115 | 81 |

| | MODIFIED W/7, 8 & 10 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 307 | 263 | 227 | 184 | 87 | 37 | 22 | 14 | 9 |
| Sulfates | 223 | 180 | 160 | 131 | 69 | 33 | 22 | 16 | 9 |
| TDS | 989 | 852 | 788 | 639 | 376 | 186 | 144 | 107 | 76 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 337 | 289 | 249 | 203 | 96 | 40 | 24 | 16 | 10 |
| Sulfates | 245 | 198 | 176 | 144 | 76 | 36 | 24 | 18 | 10 |
| TDS | 1087 | 937 | 867 | 703 | 413 | 205 | 158 | 118 | 84 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 276 | 237 | 204 | 166 | 78 | 33 | 20 | 13 | 8 |
| Sulfates | 201 | 162 | 144 | 118 | 62 | 30 | 20 | 15 | 8 |
| TDS | 890 | 767 | 709 | 575 | 338 | 167 | 129 | 96 | 69 |

| | MODIFIED W/7 & 8 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 311 | 267 | 232 | 186 | 88 | 37 | 22 | 15 | 9 |
| Sulfates | 226 | 184 | 162 | 133 | 71 | 33 | 22 | 17 | 9 |
| TDS | 1000 | 862 | 799 | 648 | 380 | 188 | 146 | 109 | 77 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 342 | 294 | 255 | 205 | 97 | 41 | 24 | 16 | 10 |
| Sulfates | 249 | 202 | 178 | 146 | 78 | 37 | 25 | 18 | 10 |
| TDS | 1100 | 948 | 878 | 712 | 418 | 207 | 160 | 119 | 85 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 280 | 240 | 208 | 168 | 79 | 33 | 20 | 13 | 8 |
| Sulfates | 204 | 166 | 146 | 120 | 64 | 30 | 20 | 15 | 8 |
| TDS | 900 | 776 | 719 | 583 | 342 | 169 | 131 | 98 | 70 |

**TABLE 2**
**HOSSTON DURATION TABLE**
**HYDROLOGIC REACH 1 - RED RIVER**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MODIFIED W/8 & 10 | | | | | | | | |
| Chlorides | 324 | 278 | 241 | 194 | 92 | 38 | 23 | 15 | 10 |
| Sulfates | 229 | 185 | 164 | 135 | 71 | 34 | 23 | 17 | 10 |
| TDS | 1028 | 884 | 820 | 665 | 389 | 193 | 150 | 112 | 79 |
| | MODIFIED + 10% | | | | | | | | |
| Chlorides | 356 | 306 | 265 | 213 | 101 | 42 | 25 | 17 | 11 |
| Sulfates | 252 | 204 | 180 | 148 | 78 | 37 | 25 | 18 | 11 |
| TDS | 1130 | 973 | 902 | 731 | 428 | 212 | 165 | 123 | 87 |
| | MODIFIED - 10% | | | | | | | | |
| Chlorides | 291 | 250 | 217 | 175 | 83 | 35 | 21 | 14 | 9 |
| Sulfates | 206 | 167 | 147 | 121 | 64 | 30 | 20 | 15 | 9 |
| TDS | 925 | 796 | 738 | 598 | 350 | 174 | 135 | 100 | 71 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MODIFIED W/8 ONLY | | | | | | | | |
| Chlorides | 329 | 282 | 244 | 197 | 93 | 39 | 23 | 15 | 10 |
| Sulfates | 232 | 189 | 167 | 137 | 72 | 34 | 23 | 17 | 10 |
| TDS | 1042 | 896 | 831 | 673 | 394 | 195 | 151 | 113 | 80 |
| | MODIFIED + 10% | | | | | | | | |
| Chlorides | 362 | 310 | 269 | 216 | 102 | 43 | 26 | 17 | 11 |
| Sulfates | 255 | 208 | 184 | 151 | 79 | 38 | 25 | 18 | 11 |
| TDS | 1146 | 985 | 914 | 740 | 433 | 215 | 167 | 124 | 88 |
| | MODIFIED – 10% | | | | | | | | |
| Chlorides | 296 | 254 | 220 | 177 | 84 | 35 | 21 | 14 | 9 |
| Sulfates | 209 | 170 | 151 | 123 | 65 | 31 | 21 | 15 | 9 |
| TDS | 938 | 806 | 748 | 605 | 355 | 176 | 136 | 102 | 72 |

**TABLE 3**

**DENISON DURATION TABLE**
**REACH 5 - RED RIVER**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | NATURAL | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 469 | 436 | 423 | 409 | 345 | 271 | 241 | 216 | 165 |
| Sulfates | 315 | 301 | 289 | 273 | 228 | 164 | 146 | 129 | 91 |
| TDS | 1294 | 1234 | 1207 | 1166 | 995 | 791 | 722 | 634 | 474 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MODIFIED W/7, 8 & 10 | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 417 | 391 | 376 | 365 | 309 | 245 | 215 | 192 | 147 |
| Sulfates | 296 | 283 | 273 | 257 | 217 | 155 | 138 | 123 | 87 |
| TDS | 1190 | 1136 | 1109 | 1075 | 921 | 730 | 665 | 582 | 435 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 459 | 430 | 414 | 402 | 340 | 270 | 237 | 211 | 162 |
| Sulfates | 326 | 311 | 300 | 283 | 239 | 170 | 152 | 135 | 96 |
| TDS | 1309 | 1250 | 1220 | 1182 | 1013 | 803 | 732 | 640 | 479 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 375 | 352 | 338 | 328 | 278 | 220 | 194 | 173 | 132 |
| Sulfates | 266 | 255 | 246 | 231 | 195 | 140 | 124 | 111 | 78 |
| TDS | 1071 | 1022 | 998 | 968 | 829 | 657 | 598 | 524 | 392 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MODIFIED W/7 & 8 | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 423 | 397 | 384 | 369 | 313 | 247 | 219 | 195 | 149 |
| Sulfates | 300 | 289 | 276 | 261 | 221 | 157 | 140 | 125 | 87 |
| TDS | 1204 | 1149 | 1124 | 1089 | 931 | 739 | 674 | 590 | 441 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 465 | 437 | 422 | 406 | 344 | 272 | 241 | 215 | 164 |
| Sulfates | 330 | 318 | 304 | 287 | 243 | 173 | 154 | 138 | 96 |
| TDS | 1324 | 1264 | 1236 | 1198 | 1024 | 813 | 741 | 649 | 485 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 381 | 357 | 346 | 332 | 282 | 222 | 197 | 176 | 134 |
| Sulfates | 270 | 260 | 248 | 235 | 199 | 141 | 126 | 112 | 78 |
| TDS | 1084 | 1034 | 1012 | 980 | 838 | 665 | 607 | 531 | 397 |

**TABLE 4**

**DENISON DURATION TABLE**
**HYDROLOGIC REACH 5 - RED RIVER**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MODIFIED W/8 & 10 | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 440 | 413 | 399 | 384 | 326 | 257 | 228 | 202 | 155 |
| Sulfates | 304 | 291 | 279 | 265 | 223 | 159 | 141 | 126 | 89 |
| TDS | 1237 | 1179 | 1154 | 1118 | 955 | 757 | 692 | 606 | 452 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 484 | 454 | 439 | 422 | 359 | 283 | 251 | 222 | 170 |
| Sulfates | 334 | 320 | 307 | 292 | 245 | 175 | 155 | 139 | 98 |
| TDS | 1361 | 1297 | 1269 | 1230 | 1050 | 833 | 761 | 667 | 497 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 396 | 372 | 359 | 346 | 293 | 231 | 205 | 182 | 140 |
| Sulfates | 274 | 262 | 251 | 238 | 201 | 143 | 127 | 113 | 80 |
| TDS | 1113 | 1061 | 1039 | 1006 | 860 | 681 | 623 | 545 | 407 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MODIFIED W/8 ONLY | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 447 | 419 | 405 | 389 | 330 | 259 | 230 | 206 | 157 |
| Sulfates | 308 | 297 | 285 | 269 | 226 | 162 | 144 | 127 | 91 |
| TDS | 1254 | 1194 | 1170 | 1131 | 966 | 766 | 700 | 613 | 458 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 492 | 461 | 446 | 428 | 363 | 285 | 253 | 227 | 173 |
| Sulfates | 339 | 327 | 314 | 296 | 249 | 178 | 158 | 140 | 100 |
| TDS | 1379 | 1313 | 1287 | 1244 | 1063 | 843 | 770 | 674 | 504 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 402 | 377 | 364 | 350 | 297 | 233 | 207 | 185 | 141 |
| Sulfates | 277 | 267 | 256 | 242 | 203 | 146 | 130 | 114 | 82 |
| TDS | 1129 | 1075 | 1053 | 1018 | 869 | 689 | 630 | 552 | 412 |

**TABLE 5**

**GAINESVILLE DURATION TABLE**
**HYDROLOGIC REACH 6 - RED RIVER**

| | NATURAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1905 | 1650 | 1536 | 1354 | 990 | 552 | 357 | 256 | 142 |
| Sulfates | 1186 | 917 | 810 | 685 | 495 | 284 | 181 | 133 | 76 |
| TDS | 4725 | 4070 | 3750 | 3374 | 2504 | 1440 | 936 | 684 | 378 |

| | MODIFIED W/7, 8 & 10 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1692 | 1471 | 1372 | 1210 | 888 | 497 | 317 | 230 | 128 |
| Sulfates | 1152 | 867 | 756 | 641 | 463 | 266 | 167 | 124 | 70 |
| TDS | 4294 | 3710 | 3430 | 3083 | 2297 | 1319 | 853 | 626 | 342 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1861 | 1618 | 1509 | 1331 | 977 | 547 | 349 | 253 | 141 |
| Sulfates | 1267 | 954 | 832 | 705 | 509 | 293 | 184 | 136 | 77 |
| TDS | 4723 | 4081 | 3773 | 3391 | 2527 | 1451 | 938 | 689 | 376 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1523 | 1324 | 1235 | 1089 | 799 | 447 | 285 | 207 | 115 |
| Sulfates | 1037 | 780 | 680 | 577 | 417 | 239 | 150 | 112 | 63 |
| TDS | 3865 | 3339 | 3087 | 2775 | 2067 | 1187 | 768 | 563 | 308 |

| | MODIFIED W/7 & 8 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1720 | 1493 | 1394 | 1228 | 901 | 504 | 323 | 232 | 130 |
| Sulfates | 1165 | 880 | 769 | 654 | 472 | 271 | 172 | 127 | 72 |
| TDS | 4370 | 3764 | 3480 | 3134 | 2330 | 1337 | 867 | 635 | 348 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1892 | 1642 | 1533 | 1351 | 991 | 554 | 355 | 255 | 143 |
| Sulfates | 1282 | 968 | 846 | 719 | 519 | 298 | 189 | 140 | 79 |
| TDS | 4807 | 4140 | 3828 | 3447 | 2563 | 1471 | 954 | 699 | 383 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1548 | 1344 | 1255 | 1105 | 811 | 454 | 291 | 209 | 117 |
| Sulfates | 1049 | 792 | 692 | 589 | 425 | 244 | 155 | 114 | 65 |
| TDS | 3933 | 3388 | 3132 | 2821 | 2097 | 1203 | 780 | 572 | 313 |

**TABLE 6**

**GAINESVILLE DURATION TABLE**
**HYDROLOGIC REACH 6 - RED RIVER**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MODIFIED W/8 & 10 | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1790 | 1556 | 1450 | 1277 | 937 | 523 | 335 | 242 | 136 |
| Sulfates | 1175 | 891 | 781 | 662 | 478 | 275 | 173 | 129 | 73 |
| TDS | 4490 | 3870 | 3575 | 3219 | 2391 | 1375 | 891 | 654 | 360 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1969 | 1712 | 1595 | 1405 | 1031 | 575 | 369 | 266 | 150 |
| Sulfates | 1292 | 980 | 859 | 728 | 526 | 302 | 190 | 142 | 80 |
| TDS | 4939 | 4257 | 3933 | 3541 | 2630 | 1513 | 980 | 719 | 396 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1611 | 1400 | 1305 | 1149 | 843 | 471 | 302 | 218 | 122 |
| Sulfates | 1058 | 802 | 703 | 596 | 430 | 248 | 156 | 116 | 66 |
| TDS | 4041 | 3483 | 3218 | 2897 | 2152 | 1238 | 802 | 589 | 324 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MODIFIED W/8 ONLY | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1817 | 1577 | 1470 | 1284 | 950 | 530 | 341 | 244 | 138 |
| Sulfates | 1184 | 908 | 796 | 674 | 486 | 279 | 177 | 131 | 75 |
| TDS | 4545 | 3926 | 3628 | 3263 | 2426 | 1393 | 902 | 660 | 364 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1999 | 1735 | 1617 | 1412 | 1045 | 583 | 375 | 268 | 152 |
| Sulfates | 1302 | 999 | 876 | 741 | 535 | 307 | 195 | 144 | 82 |
| TDS | 5000 | 4319 | 3991 | 3589 | 2669 | 1532 | 992 | 726 | 400 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1635 | 1419 | 1323 | 1156 | 855 | 477 | 307 | 220 | 124 |
| Sulfates | 1066 | 817 | 716 | 607 | 437 | 251 | 159 | 118 | 68 |
| TDS | 4090 | 3533 | 3265 | 2937 | 2183 | 1254 | 812 | 594 | 328 |

**TABLE 7**

**TERRAL DURATION TABLE**
**HYDROLOGIC REACH 7 - RED RIVER**

| | NATURAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 2129 | 1833 | 1700 | 1500 | 1183 | 684 | 442 | 317 | 164 |
| Sulfates | 1024 | 907 | 850 | 785 | 632 | 391 | 268 | 191 | 107 |
| TDS | 5290 | 4576 | 4258 | 3845 | 3053 | 1824 | 1192 | 852 | 466 |

| | MODIFIED W/7, 8 & 10 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1870 | 1607 | 1496 | 1329 | 1048 | 607 | 393 | 282 | 148 |
| Sulfates | 964 | 848 | 794 | 728 | 591 | 366 | 252 | 179 | 100 |
| TDS | 4507 | 3955 | 3655 | 3344 | 2716 | 1667 | 1116 | 804 | 438 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 2057 | 1768 | 1646 | 1462 | 1153 | 668 | 432 | 310 | 163 |
| Sulfates | 1060 | 933 | 873 | 801 | 650 | 403 | 277 | 197 | 110 |
| TDS | 4957 | 4351 | 4020 | 3678 | 2988 | 1833 | 1228 | 884 | 482 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1683 | 1446 | 1346 | 1196 | 943 | 546 | 354 | 254 | 133 |
| Sulfates | 868 | 763 | 715 | 655 | 532 | 329 | 227 | 161 | 90 |
| TDS | 4056 | 3560 | 3289 | 3009 | 2444 | 1500 | 1005 | 723 | 394 |

| | MODIFIED W/7 & 8 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1900 | 1636 | 1520 | 1350 | 1065 | 615 | 400 | 286 | 149 |
| Sulfates | 985 | 864 | 809 | 743 | 602 | 373 | 256 | 182 | 102 |
| TDS | 4591 | 4021 | 3724 | 3396 | 2754 | 1695 | 1135 | 822 | 446 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 2090 | 1800 | 1672 | 1485 | 1172 | 676 | 440 | 315 | 164 |
| Sulfates | 1084 | 950 | 890 | 817 | 662 | 410 | 282 | 200 | 112 |
| TDS | 5050 | 4423 | 4096 | 3735 | 3030 | 1864 | 1249 | 904 | 491 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1710 | 1472 | 1368 | 1215 | 958 | 554 | 360 | 257 | 134 |
| Sulfates | 886 | 778 | 728 | 669 | 542 | 336 | 230 | 164 | 92 |
| TDS | 4132 | 3619 | 3351 | 3056 | 2479 | 1525 | 1022 | 740 | 401 |

**TABLE 8**

**TERRAL DURATION TABLE**
**HYDROLOGIC REACH 7 - RED RIVER**

| | MODIFIED W/8 & 10 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1986 | 1712 | 1590 | 1408 | 1112 | 642 | 416 | 296 | 156 |
| Sulfates | 999 | 876 | 821 | 754 | 611 | 378 | 260 | 185 | 104 |
| TDS | 4729 | 4147 | 3845 | 3503 | 2841 | 1745 | 1169 | 842 | 461 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 2185 | 1883 | 1749 | 1549 | 1223 | 706 | 458 | 326 | 172 |
| Sulfates | 1099 | 964 | 903 | 829 | 672 | 416 | 286 | 204 | 114 |
| TDS | 5201 | 4562 | 4229 | 3853 | 3125 | 1919 | 1286 | 926 | 507 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1787 | 1541 | 1431 | 1267 | 1001 | 578 | 374 | 266 | 140 |
| Sulfates | 899 | 788 | 739 | 679 | 550 | 340 | 234 | 166 | 94 |
| TDS | 4256 | 3732 | 3460 | 3152 | 2557 | 1570 | 1052 | 758 | 415 |

| | MODIFIED W/8 ONLY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 2018 | 1741 | 1615 | 1430 | 1128 | 650 | 422 | 302 | 158 |
| Sulfates | 1014 | 893 | 837 | 769 | 621 | 386 | 264 | 188 | 106 |
| TDS | 4839 | 4267 | 3935 | 3594 | 2900 | 1761 | 1169 | 848 | 461 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 2220 | 1915 | 1777 | 1573 | 1241 | 715 | 464 | 332 | 174 |
| Sulfates | 1115 | 982 | 921 | 846 | 683 | 425 | 290 | 207 | 117 |
| TDS | 5322 | 4694 | 4328 | 3953 | 3190 | 1937 | 1286 | 932 | 507 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1816 | 1567 | 1454 | 1287 | 1015 | 585 | 380 | 272 | 142 |
| Sulfates | 913 | 804 | 753 | 692 | 559 | 347 | 238 | 169 | 95 |
| TDS | 4355 | 3840 | 3541 | 3234 | 2610 | 1585 | 1052 | 763 | 415 |

**TABLE 9**

**WICHITA FALLS DURATION TABLE**
**HYDROLOGIC REACH 8 - WICHITA RIVER**

| | NATURAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 2802 | 2454 | 2264 | 2065 | 1656 | 1178 | 784 | 534 | 238 |
| Sulfates | 1282 | 1025 | 925 | 798 | 598 | 436 | 292 | 200 | 90 |
| TDS | 6650 | 5790 | 5340 | 4893 | 3898 | 2812 | 1868 | 1266 | 557 |

| | MODIFIED W/7,8 & 10 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 967 | 830 | 758 | 673 | 511 | 338 | 238 | 164 | 64 |
| Sulfates | 522 | 416 | 376 | 323 | 243 | 178 | 119 | 81 | 37 |
| TDS | 2350 | 2020 | 1850 | 1656 | 1316 | 927 | 646 | 433 | 184 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1064 | 913 | 834 | 740 | 562 | 372 | 262 | 180 | 70 |
| Sulfates | 574 | 458 | 414 | 355 | 267 | 196 | 131 | 89 | 41 |
| TDS | 2585 | 2222 | 2035 | 1822 | 1448 | 1020 | 711 | 476 | 202 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 870 | 747 | 682 | 606 | 460 | 304 | 214 | 148 | 58 |
| Sulfates | 470 | 374 | 338 | 291 | 219 | 160 | 107 | 73 | 33 |
| TDS | 2115 | 1818 | 1665 | 1490 | 1184 | 834 | 581 | 390 | 166 |

| | MODIFIED W/7 & 8 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1192 | 1023 | 935 | 832 | 645 | 441 | 312 | 210 | 86 |
| Sulfates | 710 | 567 | 513 | 448 | 338 | 247 | 165 | 113 | 52 |
| TDS | 2998 | 2580 | 2367 | 2134 | 1718 | 1221 | 834 | 554 | 238 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1311 | 1125 | 1028 | 915 | 710 | 485 | 343 | 231 | 95 |
| Sulfates | 781 | 624 | 564 | 493 | 372 | 272 | 182 | 124 | 57 |
| TDS | 3298 | 2838 | 2604 | 2347 | 1890 | 1343 | 917 | 609 | 262 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1073 | 921 | 842 | 749 | 580 | 397 | 281 | 189 | 77 |
| Sulfates | 639 | 510 | 462 | 403 | 304 | 222 | 148 | 102 | 47 |
| TDS | 2698 | 2322 | 2130 | 1921 | 1546 | 1099 | 751 | 499 | 214 |

**TABLE 10**
**WICHITA FALLS DURATION TABLE**
**HYDROLOGIC REACH 8 - WICHITA RIVER**

| | MODIFIED W/8 & 10 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1806 | 1552 | 1431 | 1296 | 1048 | 738 | 502 | 339 | 148 |
| Sulfates | 886 | 706 | 636 | 554 | 406 | 296 | 199 | 136 | 62 |
| TDS | 4285 | 3724 | 3442 | 3143 | 2530 | 1813 | 1217 | 823 | 362 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1987 | 1707 | 1574 | 1426 | 1153 | 812 | 552 | 373 | 163 |
| Sulfates | 975 | 777 | 700 | 609 | 447 | 326 | 219 | 150 | 68 |
| TDS | 4714 | 4096 | 3786 | 3457 | 2783 | 1994 | 1339 | 905 | 398 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1625 | 1397 | 1288 | 1166 | 943 | 664 | 452 | 305 | 133 |
| Sulfates | 797 | 635 | 572 | 499 | 365 | 266 | 179 | 122 | 56 |
| TDS | 3856 | 3352 | 3098 | 2829 | 2277 | 1632 | 1095 | 741 | 326 |

| | MODIFIED W/8 ONLY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 2032 | 1748 | 1614 | 1465 | 1182 | 836 | 565 | 382 | 166 |
| Sulfates | 1072 | 858 | 772 | 667 | 500 | 365 | 244 | 168 | 76 |
| TDS | 4950 | 4304 | 3982 | 3632 | 2920 | 2098 | 1402 | 946 | 418 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 2235 | 1923 | 1775 | 1612 | 1300 | 920 | 622 | 420 | 183 |
| Sulfates | 1179 | 944 | 849 | 734 | 550 | 402 | 268 | 185 | 84 |
| TDS | 5445 | 4734 | 4380 | 3995 | 3212 | 2308 | 1542 | 1041 | 460 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1829 | 1573 | 1453 | 1318 | 1064 | 752 | 508 | 344 | 149 |
| Sulfates | 965 | 772 | 695 | 600 | 450 | 328 | 220 | 151 | 68 |
| TDS | 4455 | 3874 | 3584 | 3269 | 2628 | 1888 | 1262 | 851 | 376 |

**TABLE 11**

**LAKE KEMP DURATION TABLE**
**HYDROLOGIC REACH 9 - WICHITA RIVER**

| | NATURAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1985 | 1843 | 1751 | 1628 | 1312 | 1106 | 1016 | 934 | 696 |
| Sulfates | 953 | 890 | 869 | 838 | 755 | 631 | 575 | 523 | 386 |
| TDS | 4650 | 4305 | 4115 | 3838 | 3254 | 2762 | 2515 | 2325 | 1745 |

| | MODIFIED W/7,8 & 10 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 489 | 434 | 409 | 377 | 318 | 257 | 233 | 212 | 166 |
| Sulfates | 540 | 510 | 494 | 456 | 395 | 323 | 294 | 268 | 202 |
| TDS | 1580 | 1430 | 1343 | 1275 | 1108 | 897 | 815 | 742 | 541 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 538 | 477 | 450 | 415 | 350 | 283 | 256 | 233 | 183 |
| Sulfates | 594 | 561 | 543 | 502 | 435 | 355 | 323 | 295 | 222 |
| TDS | 1738 | 1573 | 1477 | 1402 | 1219 | 987 | 897 | 816 | 595 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 440 | 391 | 368 | 339 | 286 | 231 | 210 | 191 | 149 |
| Sulfates | 486 | 459 | 445 | 410 | 356 | 291 | 265 | 241 | 182 |
| TDS | 1422 | 1287 | 1209 | 1148 | 997 | 807 | 734 | 668 | 487 |

| | MODIFIED W/7 & 8 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 648 | 601 | 568 | 528 | 431 | 361 | 328 | 301 | 227 |
| Sulfates | 633 | 601 | 584 | 554 | 491 | 407 | 369 | 337 | 250 |
| TDS | 1968 | 1818 | 1735 | 1634 | 1441 | 1193 | 1090 | 992 | 728 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 713 | 661 | 625 | 581 | 474 | 397 | 361 | 331 | 250 |
| Sulfates | 696 | 661 | 642 | 609 | 540 | 448 | 406 | 371 | 275 |
| TDS | 2165 | 2000 | 1909 | 1797 | 1585 | 1312 | 1199 | 1091 | 801 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 583 | 541 | 511 | 475 | 388 | 325 | 295 | 271 | 204 |
| Sulfates | 570 | 541 | 526 | 499 | 442 | 366 | 332 | 303 | 225 |
| TDS | 1771 | 1636 | 1562 | 1471 | 1297 | 1074 | 981 | 893 | 655 |

**TABLE 12**
**LAKE KEMP DURATION TABLE**
**HYDROLOGIC REACH 9 - WICHITA RIVER**

| | MODIFIED W/8 & 10 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1170 | 1080 | 1027 | 951 | 776 | 651 | 596 | 545 | 406 |
| Sulfates | 725 | 687 | 669 | 633 | 562 | 467 | 423 | 385 | 290 |
| TDS | 2954 | 2735 | 2606 | 2438 | 2115 | 1763 | 1607 | 1471 | 1094 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1287 | 1188 | 1130 | 1046 | 854 | 716 | 656 | 600 | 447 |
| Sulfates | 798 | 756 | 736 | 696 | 618 | 514 | 465 | 424 | 319 |
| TDS | 3249 | 3009 | 2867 | 2682 | 2326 | 1939 | 1768 | 1618 | 1203 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1053 | 972 | 924 | 856 | 698 | 586 | 536 | 490 | 365 |
| Sulfates | 652 | 618 | 602 | 570 | 506 | 420 | 381 | 346 | 261 |
| TDS | 2659 | 2462 | 2345 | 2194 | 1904 | 1587 | 1446 | 1324 | 985 |

| | MODIFIED W/8 ONLY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1340 | 1245 | 1187 | 1100 | 891 | 751 | 690 | 630 | 470 |
| Sulfates | 829 | 781 | 763 | 733 | 657 | 547 | 497 | 454 | 335 |
| TDS | 3425 | 3157 | 3020 | 2825 | 2422 | 2050 | 1862 | 1718 | 1270 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1474 | 1370 | 1306 | 1210 | 980 | 826 | 759 | 693 | 517 |
| Sulfates | 912 | 859 | 839 | 806 | 723 | 602 | 547 | 499 | 369 |
| TDS | 3768 | 3473 | 3322 | 3108 | 2664 | 2255 | 2048 | 1890 | 1397 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 1206 | 1120 | 1068 | 990 | 802 | 676 | 621 | 567 | 423 |
| Sulfates | 746 | 703 | 687 | 660 | 591 | 492 | 447 | 409 | 302 |
| TDS | 3082 | 2841 | 2718 | 2542 | 2180 | 1845 | 1676 | 1546 | 1143 |

**TABLE 13**

**TRUSCOTT DURATION TABLE**
**HYDROLOGIC REACH 10 - N. WICHITA RIVER**

| | NATURAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 9812 | 8187 | 7340 | 6335 | 4965 | 3201 | 2056 | 1230 | 410 |
| Sulfates | 3860 | 3240 | 2960 | 2643 | 2284 | 1691 | 1190 | 800 | 325 |
| TDS | 22500 | 18875 | 16560 | 14325 | 11455 | 7800 | 5250 | 3275 | 1200 |

| | MODIFIED W/Areas 7 & 10 IN PLACE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 7600 | 4180 | 2440 | 1682 | 1197 | 585 | 127 | 0 | 0 |
| Sulfates | 3170 | 2395 | 1600 | 1145 | 910 | 530 | 160 | 0 | 0 |
| TDS | 17350 | 10750 | 6550 | 4505 | 3285 | 1735 | 450 | 0 | 0 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 8360 | 4598 | 2684 | 1850 | 1317 | 644 | 140 | 0 | 0 |
| Sulfates | 3487 | 2634 | 1760 | 1260 | 1001 | 583 | 176 | 0 | 0 |
| TDS | 19085 | 11825 | 7205 | 4956 | 3614 | 1909 | 495 | 0 | 0 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 6840 | 3762 | 2196 | 1514 | 1077 | 526 | 114 | 0 | 0 |
| Sulfates | 2853 | 2156 | 1440 | 1030 | 819 | 477 | 144 | 0 | 0 |
| TDS | 15615 | 9675 | 5895 | 4054 | 2956 | 1562 | 405 | 0 | 0 |

| | MODIFIED W/Area 7 ONLY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 8500 | 5375 | 3270 | 2400 | 1837 | 1113 | 626 | 270 | 0 |
| Sulfates | 3420 | 2835 | 2130 | 1627 | 1376 | 965 | 615 | 315 | 0 |
| TDS | 19100 | 13400 | 8950 | 6490 | 5070 | 3250 | 1940 | 890 | 0 |
| | MODIFIED + 10% | | | | | | | | |
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 9350 | 5913 | 3597 | 2640 | 2021 | 1224 | 689 | 297 | 0 |
| Sulfates | 3762 | 3119 | 2343 | 1790 | 1514 | 1062 | 676 | 346 | 0 |
| TDS | 21010 | 14740 | 9845 | 7139 | 5577 | 3575 | 2134 | 979 | 0 |
| | MODIFIED - 10% | | | | | | | | |
| | Percent of Time Equalled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 7650 | 4838 | 2943 | 2160 | 1653 | 1002 | 563 | 243 | 0 |
| Sulfates | 3078 | 2552 | 1917 | 1464 | 1238 | 868 | 554 | 284 | 0 |
| TDS | 17190 | 12060 | 8055 | 5841 | 4563 | 2925 | 1746 | 801 | 0 |

**TABLE 14**
**TRUSCOTT DURATION TABLE**
**HYDROLOGIC REACH 10 - N. WICHITA RIVER**

| | MODIFIED W/Area 10 ONLY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 8750 | 6975 | 6150 | 5300 | 4140 | 2610 | 1600 | 850 | 1 |
| Sulfates | 3245 | 2555 | 2300 | 2045 | 1769 | 1285 | 870 | 530 | 1 |
| TDS | 19300 | 15575 | 13450 | 11640 | 9325 | 6200 | 3985 | 2295 | 1 |

| | MODIFIED + 10% | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 9625 | 7673 | 6765 | 5830 | 4554 | 2871 | 1760 | 935 | 1.1 |
| Sulfates | 3570 | 2810 | 2530 | 2250 | 1946 | 1414 | 957 | 583 | 1.1 |
| TDS | 21230 | 17132 | 14795 | 12804 | 10258 | 6820 | 4384 | 2524 | 1.1 |

| | MODIFIED - 10% | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 7875 | 6278 | 5535 | 4770 | 3726 | 2349 | 1440 | 765 | 0.9 |
| Sulfates | 2920 | 2300 | 2070 | 1840 | 1592 | 1156 | 783 | 477 | 0.9 |
| TDS | 17370 | 14018 | 12105 | 10476 | 8392 | 5580 | 3586 | 2066 | 0.9 |

**TABLE 15**

**BENJAMIN DURATION TABLE**
**HYDROLOGIC REACH 11 - S. WICHITA RIVER**

| | NATURAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 15080 | 12900 | 11840 | 10450 | 7437 | 3002 | 1087 | 0 | 0 |
| Sulfates | 3820 | 3405 | 3240 | 3105 | 2710 | 1645 | 858 | 0 | 0 |
| TDS | 29400 | 26080 | 24040 | 21750 | 16025 | 7410 | 3110 | 0 | 0 |

| | MODIFIED W/AREA 8 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 7350 | 5750 | 4875 | 4110 | 2790 | 1053 | 185 | 0 | 0 |
| Sulfates | 3265 | 2930 | 2704 | 2447 | 1948 | 1057 | 335 | 0 | 0 |
| TDS | 17650 | 14000 | 12330 | 10700 | 7625 | 3250 | 790 | 0 | 0 |

| | MODIFIED + 10% | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 8085 | 6325 | 5363 | 4521 | 3069 | 1158 | 204 | 0 | 0 |
| Sulfates | 3592 | 3223 | 2974 | 2692 | 2143 | 1163 | 369 | 0 | 0 |
| TDS | 19415 | 15400 | 13563 | 11770 | 8388 | 3575 | 869 | 0 | 0 |

| | MODIFIED - 10% | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Percent of Time Equaled or Exceeded | | | | | | | | |
| Concentrations | 1% | 5% | 10% | 20% | 50% | 80% | 90% | 95% | 99% |
| Chlorides | 6615 | 5175 | 4388 | 3699 | 2511 | 948 | 167 | 0 | 0 |
| Sulfates | 2939 | 2637 | 2434 | 2202 | 1753 | 951 | 302 | 0 | 0 |
| TDS | 15885 | 12600 | 11097 | 9630 | 6863 | 2925 | 711 | 0 | 0 |

# EXHIBIT D

# LAKE KEMP ELEVATION DURATION CURVES

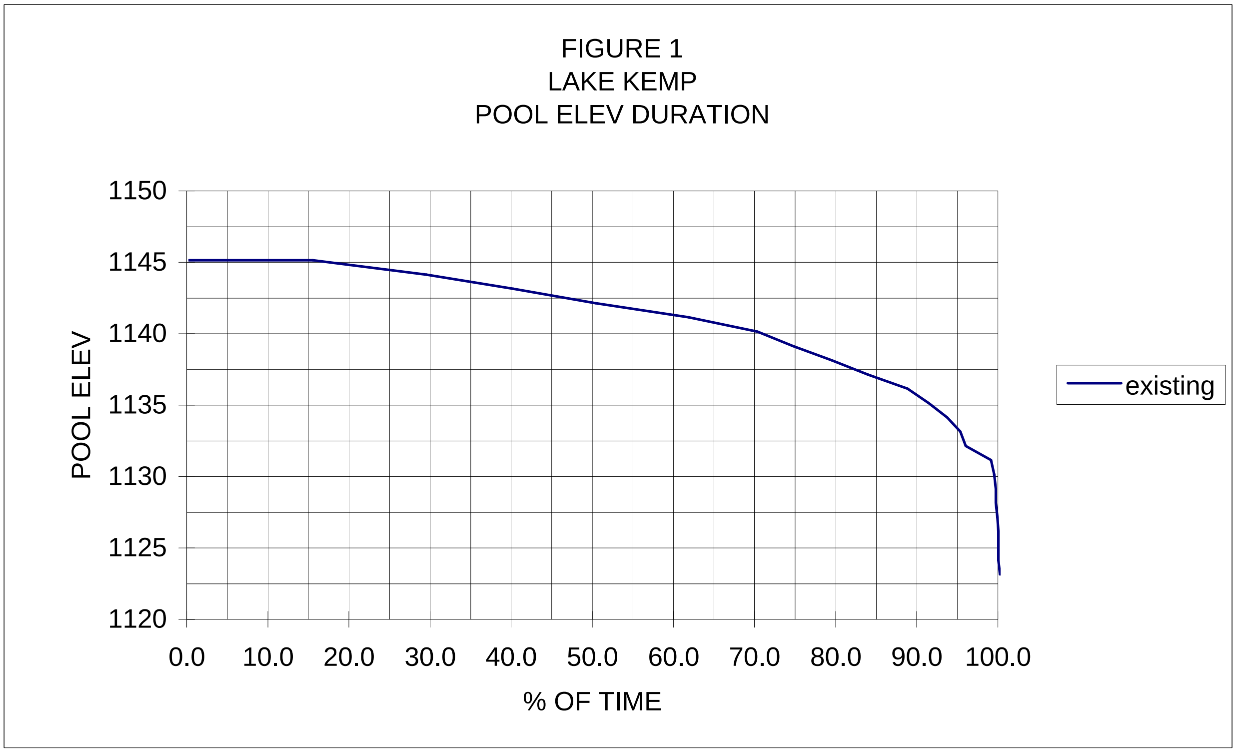



Figure 1 – Existing Conditions

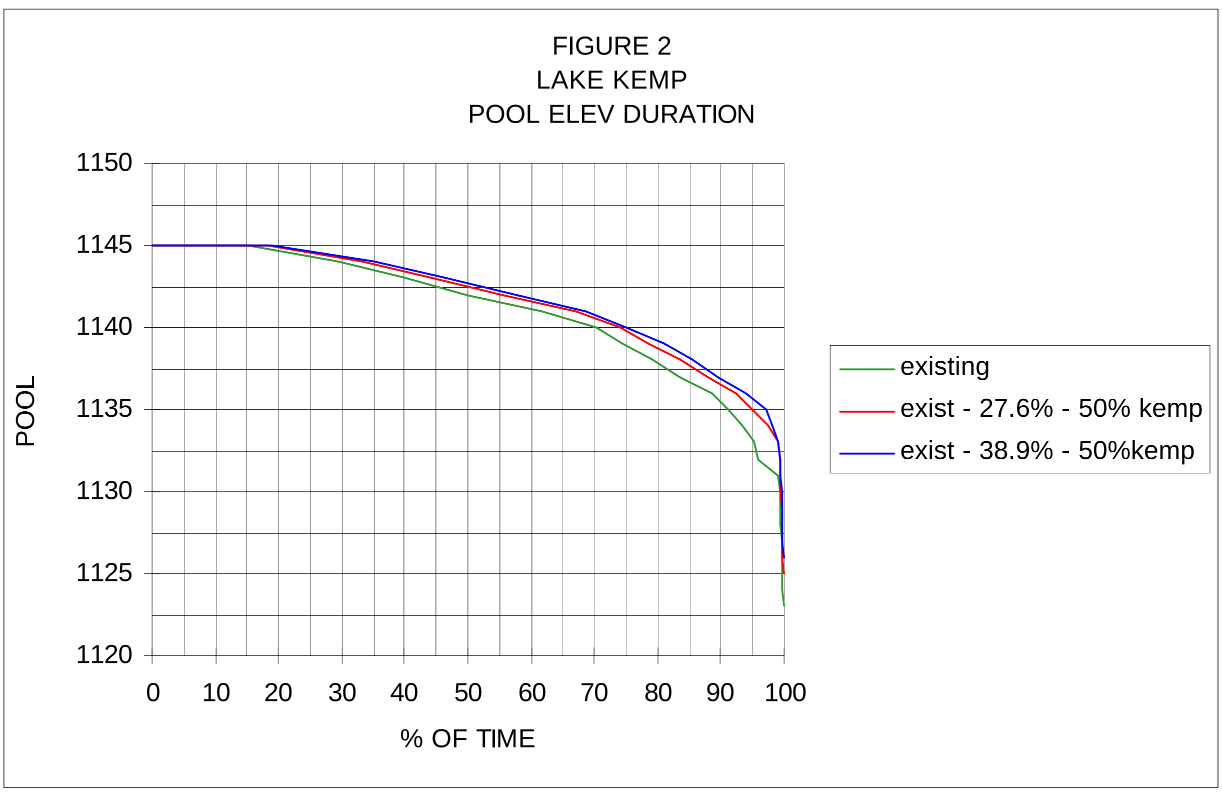



Figure 2 – Existing Conditions w/ 50% Basin B rush Control

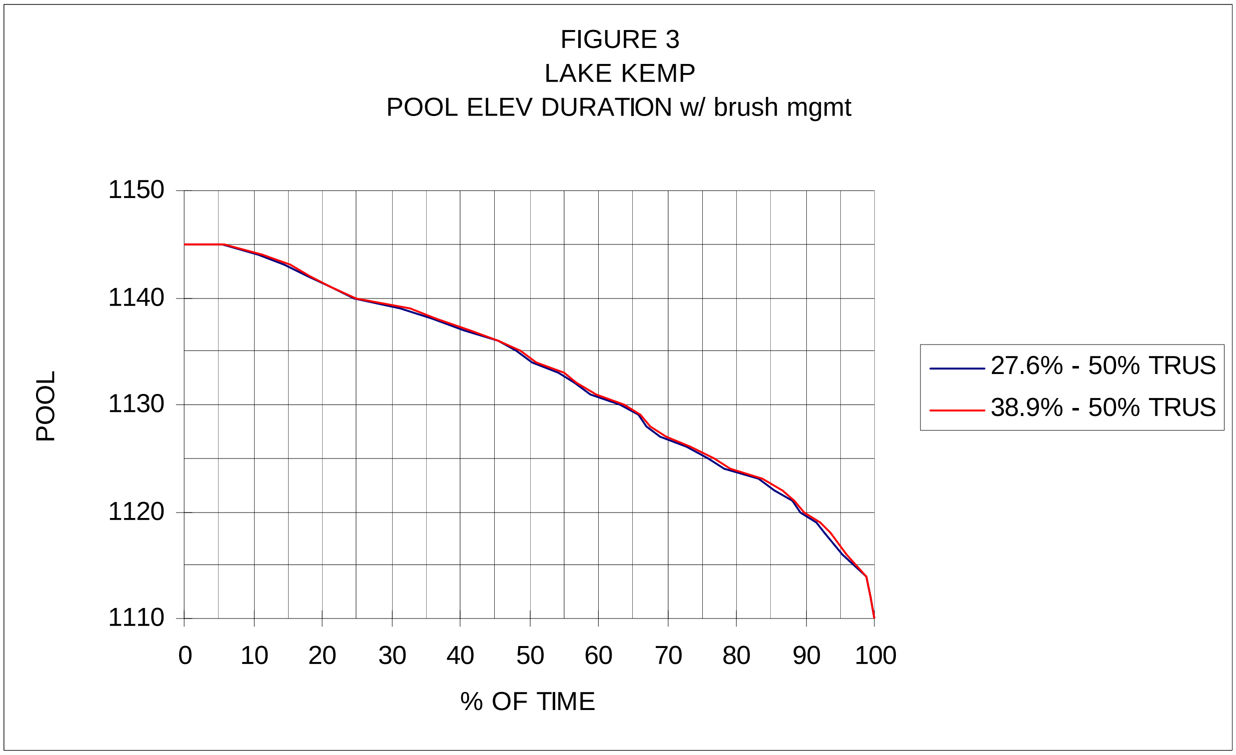



Figure 3 – Selected Plan w/ 50% Brush Control @ Truscott gage

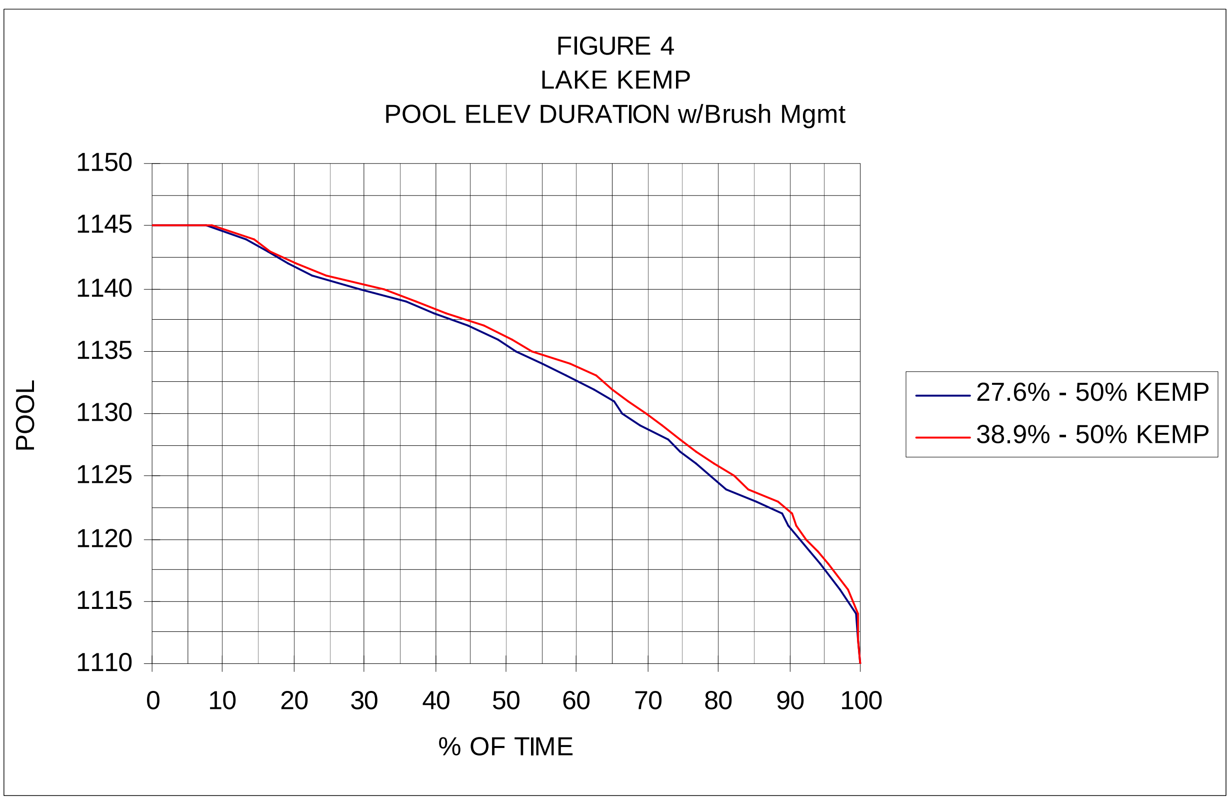



Figure 4 – Selected Plan w/ 50% Basin Brush Control

# APPENDIX A

# CONVERSION OF SPECIFIC CONDUCTANCES TO CONCENTRATIONS

## TABLE OF CONTENTS

## TABLE OF CONTENTS (Continued)

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## CONVERSION OF SPECIFIC CONDUCTANCES TO CONCENTRATIONS

### INTRODUCTION

This appendix contains detailed information about gages where the standard method of computing concentrations (as described in the main report) was not used. Tables at the back of this appendix summarize the regression constants used to convert the daily conductivities to chloride (Cl), sulfate ($SO_4$), and Total Dissolved Solids (TDS) concentrations. Five tables were required because the U.S. Geological Survey (USGS) changed the format of their regression equation in 1980.

### AREA VII/PADUCAH GAGE

For Water Years (WY) 1971-1976, daily specific conductance data were available at the Paducah gage but regression coefficients were not available. Specific conductance vs. concentration data from published sample analyses were plotted on log-log paper for each constituent. The correlations appeared to be very good. The daily concentrations were computed using these curves. The computed loads were checked with the published loads and found to be reasonable.

For WY 1996-1998, daily specific conductance and regression coefficients were available. The computed monthly totals compared favorably with the recorded totals. Since monthly totals were not available for Water Year 1995, 1996 coefficients were used. Table A-1 shows the comparison of the computed loads to the published loads.

**TABLE A-1**

**AREA VII/PADUCAH GAGE**
**PERCENT DIFFERENCE FROM USGS DATA**

| Year | Flow | Cl | $SO_4$ | TDS |
|---|---|---|---|---|
| 1971 | 0.0 | -2.8 | 5.4 | -0.6 |
| 1972 | 0.0 | -2.3 | 5.3 | -0.8 |
| 1973 | 0.0 | -2.6 | 5.9 | -0.8 |
| 1974 | 0.0 | 2.4 | 3.1 | 1.8 |
| 1975 | 0.0 | -3.1 | -0.8 | -1.9 |
| 1976 | -0.1 | 1.7 | 8.4 | 2.9 |
| 1995 | 0.0 | No Published Totals | | |
| 1996 | 0.0 | 0.4 | 0.3 | 0.4 |
| 1997 | 0.0 | 0.3 | -0.4 | 0.3 |
| 1998 | 0.0 | 0.1 | 0.1 | 0.3 |

## AREA VIII

For WY 1971-1976, daily specific conductance and monthly totals were available for the Guthrie gage. The gage was discontinued in 1977 but was reestablished in October 1984 at the Area VIII low flow dam. Two gages were actually established. One gage named Guthrie @ Low Flow Dam was used to measure the flow and conductivity of the pumped water after Truscott Brine Lake was put in operation in May 1987. This gage recorded both flow and water quality data. The period of record used for this study was WY 1985-1998. The second gage was called Guthrie Below Low Flow Dam. Its primary purpose was to determine outflows from the low flow dam. It began as a flow and water quality data gage. The water quality portion was dropped in September 1989 since conductivities from the two gages were the same. Regression coefficients and monthly totals were available for WY 1885-1998. Table A-2 shows the comparison of the computed data to the recorded data for all three gages.

**TABLE A-2**

**AREA VIII**

**PERCENT DIFFERENCE FROM USGS DATA**

| Guthrie (South Fork) | | | | |
|---|---|---|---|---|
| **Year** | **Flow** | **Cl** | **$SO_4$** | **TDS** |
| 1971 | 0.0 | 0.6 | -1.5 | 0.3 |
| 1972 | 0.0 | 0.5 | 0.6 | 0.3 |
| 1973 | 0.0 | 0.9 | -1.7 | -0.1 |
| 1974 | 0.0 | -2.3 | -8.8 | -4.2 |
| 1975 | 0.0 | -4.0 | -0.8 | -3.3 |
| 1976 | -0.3 | 2.2 | -1.2 | 0.6 |
| **Guthrie @ Low Flow Dam** | | | | |
| **Year** | **Flow** | **Cl** | **$SO_4$** | **TDS** |
| 1985 | 0.1 | -0.1 | -4.4 | -2.0 |
| 1986 | 0.0 | 4.1 | -13.4 | -3.4 |
| 1987 | 0.0 | 0.4 | 0.4 | 0.4 |
| 1988 | 0.0 | 0.5 | 0.7 | 1.0 |
| 1989 | 0.1 | 0.4 | 0.5 | 0.2 |
| 1990 | 0.0 | 0.4 | 0.2 | 0.1 |
| 1991 | 0.0 | 0.4 | 0.3 | 0.2 |
| 1992 | 0.0 | 0.4 | 0.3 | 0.4 |
| 1993 | 0.0 | 0.5 | 0.4 | 0.5 |
| 1994 | 0.0 | -0.3 | -1.7 | 0.1 |
| 1995 | 0.0 | 0.3 | 0.5 | 0.5 |
| 1996 | 0.0 | 0.4 | 0.4 | 0.4 |
| 1997 | 0.0 | 0.3 | 0.0 | 0.3 |
| 1998 | 0.0 | 0.2 | -0.4 | 0.2 |
| **Guthrie Below Low Flow Dam** | | | | |
| **Year** | **Flow** | **Cl** | **$SO_4$** | **TDS** |
| 1987 | -0.1 | 0.3 | 0.1 | 0.2 |
| 1988 | 0.7 | -2.3 | -4.4 | -8.7 |
| 1989 | -0.2 | -8.3 | 0.0 | -11.7 |

## AREA X

The Truscott gage near the mouth of the Middle Fork of the Wichita River was installed in October 1970 and operated through September 1976. Daily flow and specific conductance was recorded. Regression constants and monthly totals were available for this period. In October 1994, a gage was established near the Low Flow Dam below Area X called Guthrie. There were no monthly totals published for WY 1995 nor were there any regression constants available. The 1996 regression constants were used for the WY 1995 concentration computations. There were several instances at this gage when no daily flows were published. This generally occurred during higher flows and was probably due to equipment failure. A flow vs. conductivity correlation study was performed and the missing flows were estimated from the specific conductance. Flows and specific conductance data were available for the remaining period of WY 1996-1998. Regression constants and monthly totals were also available. Table A-3 shows the comparison of computed data to the recorded data for both gages.

**TABLE A-3**

**AREA X**
**PERCENT DIFFERENCE FROM USGS DATA**

| **Truscott (Middle Fork)** | | | | |
|---|---|---|---|---|
| **Year** | **Flow** | **Cl** | **$SO_4$** | **TDS** |
| 1971 | 0.4 | 0.1 | 0.4 | -0.1 |
| 1972 | 0.0 | 0.1 | -0.3 | 0.1 |
| 1973 | 6.1 | 1.6 | 1.7 | 1.2 |
| 1974 | 0.0 | 0.0 | 0.2 | -0.1 |
| 1975 | 0.0 | -0.0 | 0.2 | -0.0 |
| 1976 | -0.2 | -0.1 | 0.1 | 0.1 |
| **Guthrie (Middle Fork)** | | | | |
| **Year** | **Flow** | **Cl** | **$SO_4$** | **TDS** |
| 1996 | 0.0 | 0.2 | 1.4 | 0.3 |
| 1997 | 0.0 | 0.3 | 0.0 | 0.3 |
| 1998 | 0.0 | 0.3 | -0.0 | 0.3 |

## BENJAMIN GAGE

The Benjamin gage on the South Fork of the Wichita River had continuous daily-recorded flow and specific conductance data for the entire study period. Data prior to WY 1988 had already been computed prior to the beginning of this study. These data were also used in this study. Table A-4 shows the percent differences between the computed loads and the USGS published loads for WY 1988-1998.

## TABLE A-4

## BENJAMIN GAGE
## PERCENT DIFFERENCE FROM USGS DATA

| Year | Flow | Cl | $SO_4$ | TDS |
|---|---|---|---|---|
| 1988 | 0.0 | 4.0 | 6.0 | 0.9 |
| 1989 | 0.0 | 0.2 | 0.4 | 0.3 |
| 1990 | 0.0 | 0.4 | 0.4 | 0.4 |
| 1991 | 0.0 | 0.3 | 0.4 | 0.6 |
| 1992 | 0.0 | 0.4 | 0.4 | 0.2 |
| 1993 | 0.0 | 0.4 | 0.3 | 0.2 |
| 1994 | 0.0 | 0.1 | 11.4 | 0.7 |
| 1995 | 0.0 | 2.2 | 1.9 | 2.0 |
| 1996 | 0.0 | 0.2 | 0.5 | 3.3 |
| 1997 | 0.0 | 0.1 | 0.1 | 0.3 |
| 1998 | 0.0 | 0.5 | 0.1 | 0.2 |

## TRUSCOTT (NORTH FORK) GAGE

Data were computed from WY 1975-1998. The WY 1975-1977 data were computed during the design phase. A comparison of both data sets revealed that the recomputed data matched the USGS monthly totals more closely. Therefore, the recomputed data for WY 1975-1977 were used. Consequently, the regression coefficients for WY 1975 are shown then skips to WY 1978. The coefficients for 1984 and 1985 were not available from the USGS. Rather than plot the data and make a best fit curve from a specific conductance correlation with Cl, $SO_4$, and TDS, the 1983 and the 1986 coefficients were both used to compute the 1984-1985 concentrations. The concentrations that more closely reproduced the monthly loads were used. Table A-5 indicates which years' coefficients provided the closest monthly totals for each parameter.

**TABLE A-5**

**TRUSCOTT (NORTH FORK) GAGE**
**COEFFICIENTS USED FOR WATER YEARS 1984-1985**

| Mo/Yr | Cl | $SO_4$ | TDS |
|---|---|---|---|
| 10-83 | 2 | 1 | 2 |
| 11-83 | 2 | 1 | 2 |
| 12-83 | 2 | 1 | 2 |
| 1-84 | 2 | 1 | 2 |
| 2-84 | 1 | 2 | 2 |
| 3-84 | 1 | 2 | 1 |
| 4-84 | 1 | 2 | 1 |
| 5-84 | 1 | 2 | 1 |
| 6-84 | 1 | 2 | 1 |
| 7-84 | 1 | 2 | 1 |
| 8-84 | 2 | 1 | 2 |
| 9-84 | 2 | 1 | 2 |
| 10-84 | 1 | 2 | 2 |
| 11-84 | 1 | 2 | 2 |
| 12-84 | 2 | 1 | 2 |
| 1-85 | 1 | 2 | 2 |
| 2-85 | 1 | 2 | 1 |
| 3-85 | 2 | 1 | 2 |
| 4-85 | 1 | 2 | 2 |
| 5-85 | 1 | 2 | 1 |
| 6-85 | 2 | 1 | 2 |
| 7-85 | 1 | 2 | 1 |
| 8-85 | 1 | 2 | 1 |
| 9-85 | 1 | 2 | 1 |

1 = Water Year 1983 coefficients.
2 = Water Year 1986 coefficients.

**SEYMOUR GAGE**

Data prior to WY 1978 were computed in a previous study. Specific conductance and flow data were available for WY 1978-1979. Correlation coefficients were obtained from the USGS. The sulfate correlation values were not decipherable for WY 1978; therefore, WY 1979 sulfate values were used. The daily specific conductance data were converted to daily Cl, $SO_4$, and TDS concentrations. These data were converted to daily loads and summed to obtain monthly totals. The monthly loads were compared to published USGS monthly loads for each constituent. The data for WY 1978 did not check out for the chlorides. The coefficients were double checked for accuracy. Since the 1979 data checked out okay, the 1979 coefficients were used for Cl and TDS for 1978. The chlorides correlated better, although some months were still off by 20-50%. Next, a log-log plot of the samples listed in the USGS Water Supply Papers was made. Values used to define the log-log curve are shown in Table A-6.

**TABLE A-6**

**SEYMOUR GAGE**
**LOG-LOG CURVE DEFINITION POINTS**

| Water Year | Cl1 | CondC1 | Cl2 | CondC2 |
|---|---|---|---|---|
| 1978 | 10 | 120 | 10000 | 31000 |

The equations used were:

SLOPE = (LOG(CL1)-LOG(CL2))/(LOG(CONDC1)-LOG(CONDC2))
NEWCL = LOG(CL1)-SLOPE*(LOG(CONDC1)-LOG(COND))
Where COND = daily average specific conductivity

A best fit line was drawn and the data recomputed. After some adjustments, a best fit was selected. Using the results of all three computations, the best data for each parameter were selected. Table A-7 shows the methods used for each month.

**TABLE A-7**

**SEYMOUR GAGE**
**SOURCE OF DATA FOR WATER QUALITY PARAMETERS**
**(WATER YEAR 1978)**

| Month | Cl | $SO_4$ | TDS |
|---|---|---|---|
| October | 2 | 3 | 1 |
| November | 2 | 2 | 1 |
| December | 2 | 2 | 1 |
| January | 2 | 2 | 1 |
| February | 2 | 3 | 1 |
| March | 2 | 2 | 1 |
| April | 2 | 2 | 1 |
| May | 2 | 3 | 1 |
| June | 3 | 3 | 1 |
| July | 2 | 3 | 1 |
| August | 3 | 2 | 1 |
| September | 3 | 3 | 1 |

1 = 1978 Coefficients
2 = 1979 Coefficients
3 = Log-Log Plot

Table A-8 shows the percent difference from the USGS published data for the above computations plus WY 1998. There were no published totals for WY 1997.

**TABLE A-8**

**SEYMOUR GAGE**
**PERCENT DIFFERENCE**

| Date | Flow | Cl | $SO_4$ | TDS |
|---|---|---|---|---|
| 103177 | 0.0 | -3.0 | -7.0 | 0.2 |
| 113077 | 0.0 | 0.2 | 1.5 | 0.6 |
| 123177 | 0.0 | 0.3 | 2.1 | 0.5 |
| 13178 | 0.0 | -0.1 | 1.8 | 0.6 |
| 22878 | 0.0 | -0.3 | -0.3 | 0.2 |
| 33178 | 0.0 | 0.6 | 1.7 | 0.2 |
| 43078 | -0.3 | 0.4 | 2.3 | 0.5 |
| 53178 | 0.0 | -5.6 | -7.2 | 0.3 |
| 63078 | 0.0 | 9.1 | -2.6 | 0.4 |
| 73178 | 0.1 | -1.3 | -2.9 | 0.3 |
| 83178 | 0.0 | -5.4 | 1.5 | 0.3 |
| 93078 | 0.0 | 8.6 | -4.1 | 0.5 |
| 103178 | 0.0 | 0.8 | 0.4 | 0.6 |
| 113078 | 0.0 | 0.5 | 0.2 | 0.4 |
| 123178 | 0.0 | 0.0 | 0.4 | 0.5 |
| 13179 | 0.0 | 0.3 | 0.4 | 0.5 |
| 22879 | 0.0 | 0.4 | 0.4 | 0.5 |
| 33179 | 0.0 | 0.7 | 0.3 | 0.4 |
| 43079 | 0.0 | 0.2 | 0.3 | 0.2 |
| 53179 | 0.0 | 0.7 | 0.1 | 0.4 |
| 63079 | 0.0 | 0.2 | 0.0 | 0.5 |
| 73179 | 0.0 | 0.1 | 0.3 | 0.3 |
| 83179 | 0.0 | 0.6 | -0.3 | 0.5 |
| 93079 | 0.0 | 0.4 | 0.4 | 0.2 |
| WY 1998 | 0.0 | 0.2 | 0.2 | 0.3 |

## MABELLE GAGE

Water quality data were computed for WY 1978-1998. Specific conductance data were not available for May 1993 through September 1994. Regression coefficients were available for all WY except WY 1984-1985. Rather than plot the data and make a best fit curve from a specific conductance correlation with concentrations, the 1983 coefficients and the 1986 coefficients were both used to compute the 1984-1985 concentrations. The concentrations that more closely reproduced the published USGS monthly loads were used. Table A-9 indicates which coefficient provided the closest monthly totals for each parameter.

## TABLE A-9

## MABELLE GAGE
## COEFFICIENTS USED FOR WATER YEARS 1984-1985

| Date | Cl | $SO_4$ | TDS |
|---|---|---|---|
| 103183 | 2 | 1 | 1 |
| 113083 | 2 | 1 | 1 |
| 123183 | 2 | 1 | 1 |
| 13184 | 2 | 1 | 1 |
| 22984 | 2 | 1 | 1 |
| 33184 | 2 | 1 | 1 |
| 43084 | 2 | 1 | 1 |
| 53184 | 2 | 1 | 1 |
| 63084 | 2 | 1 | 1 |
| 73184 | 2 | 1 | 2 |
| 83184 | 2 | 2 | 2 |
| 93084 | 2 | 2 | 1 |
| 103184 | 2 | 2 | 1 |
| 113084 | 2 | 1 | 1 |
| 123184 | 2 | 1 | 1 |
| 13185 | 2 | 1 | 2 |
| 22885 | 2 | 1 | 2 |
| 33185 | 2 | 1 | 1 |
| 43085 | 2 | 1 | 2 |
| 53185 | 2 | 1 | 1 |
| 63085 | 2 | 1 | 2 |
| 73185 | 2 | 1 | 2 |
| 83185 | 2 | 1 | 2 |
| 93085 | 2 | 1 | 2 |

1 = Water Year 1983 coefficients.
2 = Water Year 1986 coefficients.

Table A-10 shows the percent differences between the computed loads and the USGS published monthly loads for WY 1984-1985. The percent differences were computed as (published-computed)/published*100.

## TABLE A-10

## MABELLE GAGE
## PERCENT DIFFERENCE FROM USGS DATA
## (WATER YEARS 1984-1985)

| Date | CL | $SO_4$ | TDS |
|---|---|---|---|
| 103183 | 0.5 | 0.4 | 0.5 |
| 113083 | 1.1 | -0.1 | 0.8 |
| 123183 | 1.0 | -0.3 | 0.5 |
| 13184 | 1.1 | 0.3 | 0.7 |
| 22984 | 0.8 | 0.3 | 0.4 |
| 33184 | 0.7 | 0.0 | 0.4 |
| 43084 | 0.6 | 0.1 | 0.2 |
| 53184 | 0.4 | 0.5 | 0.2 |
| 63084 | 0.1 | 0.5 | 0.2 |
| 73184 | 0.0 | 0.3 | 0.0 |
| 83184 | -0.2 | 0.5 | 0.1 |
| 93084 | -0.2 | 0.3 | 0.1 |
| 103184 | 0.0 | 0.2 | -0.3 |
| 113084 | 1.3 | 1.0 | 0.8 |
| 123184 | 1.8 | 0.4 | 1.3 |
| 13185 | 0.1 | 0.5 | 0.0 |
| 22885 | 0.1 | 0.1 | 0.0 |
| 33185 | 0.8 | -0.1 | 0.5 |
| 43085 | -0.1 | 0.4 | 0.1 |
| 53185 | 0.1 | 0.3 | 0.0 |
| 63085 | 0.1 | 0.2 | 0.4 |
| 73185 | 0.3 | 0.0 | 0.1 |
| 83185 | 0.1 | 0.1 | 0.1 |
| 93085 | 0.1 | 0.0 | 0.1 |

Table A-11 shows the percent difference between the computed loads and the published USGS monthly totals for WY 1978 through May 1993 and WY 1995-1996. The percent difference was computed as (published-computed)/published*100.

**TABLE A-11**

**MABELLE GAGE**
**PERCENT DIFFERENCE FROM USGS DATA**
**(WATER YEARS 1978 - MAY 1993, WATER YEARS 1995-1996)**

| Year | Flow | Cl | $SO_4$ | TDS |
|---|---|---|---|---|
| 1978 | 0.0 | 0.5 | 0.5 | 0.3 |
| 1979 | 0.0 | 0.0 | 0.2 | 0.3 |
| 1980 | 0.0 | 0.4 | 0.6 | -6.1 |
| 1981 | 0.0 | 1.0 | 0.4 | -5.1 |
| 1982 | 0.0 | 0.4 | 0.4 | 0.5 |
| 1983 | 0.0 | 0.6 | 0.4 | 0.5 |
| 1984 | 0.0 | 0.6 | 0.4 | 0.3 |
| 1985 | 0.0 | 0.4 | 0.3 | 0.2 |
| 1986 | 0.0 | 0.6 | 0.1 | 0.3 |
| 1987 | 0.0 | 0.4 | 0.3 | 0.4 |
| 1988 | 0.0 | 0.1 | 0.3 | 0.5 |
| 1989 | 0.0 | 0.0 | 0.4 | 0.3 |
| 1990 | 0.0 | 0.4 | 0.6 | 0.4 |
| 1991 | 0.0 | 0.6 | 0.3 | 0.3 |
| 1992 | 0.0 | 0.3 | 0.5 | 0.4 |
| 1993 | 0.0 | 0.4 | 0.4 | 0.2 |
| 1994 | | no data | | |
| 1995 | 0.0 | 0.4 | 0.5 | 0.1 |
| 1996 | 0.0 | 0.6 | 0.4 | 0.4 |
| 1997 | 0.0 | 0.2 | 0.3 | 0.3 |
| 1998 | 0.0 | 0.3 | 0.3 | 0.4 |

## WICHITA FALLS GAGE

Flow and specific conductance data were available for WY 1982-1989. Table A-12 shows the percent difference between the computed loads and published USGS data. The percent difference was calculated as (published-computed)/published*100.

**TABLE A-12**

**WICHITA FALLS GAGE**
**PERCENT DIFFERENCE FROM USGS DATA**

| Water Year | Flows | Cl | $SO_4$ | TDS |
|---|---|---|---|---|
| 1982 | 0.0% | 0.3% | 0.3% | 0.4% |
| 1983 | 0.0% | 0.4% | 0.4% | 0.2% |
| 1984 | 0.0% | 0.3% | 2.2% | 0.2% |
| 1985 | 0.0% | -1.1% | 1.5% | -1.0% |
| 1986 | 0.0% | 0.4% | 0.5% | 0.5% |
| 1987 | 0.0% | 0.4% | 0.3% | 0.1% |
| 1988 | 0.0% | 0.7% | 0.5% | -2.3% |
| 1989 | 0.0% | 0.1% | 0.4% | -1.9% |

The WY 1997-1998 data did not include monthly totals. Daily specific conductance data were available but regression coefficients were not available. Therefore, daily concentrations were computed from a correlation of specific conductance vs. concentration using USGS grab sample analyses. There was no way to verify the accuracy of the computed loads because the USGS monthly totals were not available for comparison.

## TERRAL GAGE

Data prior to WY 1974 were computed in a previous study. Specific conductance and flow data were available for WY 1974-1997. Regression coefficients were available for all years except WY 1984-1985. Rather than plot up the data and make a best guess curve from a specific conductance correlation with Cl, $SO_4$, and TDS, the 1983 coefficients and the 1986 coefficients were both used to compute the WY 1984-1985 concentrations. The concentrations that more closely reproduced the published USGS monthly loads were used. Table A-13 indicates which coefficients provided the closest monthly totals for each parameter.

## TABLE A-13

## TERRAL GAGE
## COEFFICIENTS USED FOR WATER YEARS 1984-1985

| Month | Year | Cl | $SO_4$ | TDS |
|---|---|---|---|---|
| 10 | 83 | 1 | 1 | 1 |
| 11 | 83 | 1 | 1 | 2 |
| 12 | 83 | 1 | 1 | 2 |
| 1 | 84 | 1 | 1 | 2 |
| 2 | 84 | 1 | 1 | 2 |
| 3 | 84 | 1 | 1 | 2 |
| 4 | 84 | 1 | 1 | 2 |
| 5 | 84 | 1 | 1 | 2 |
| 6 | 84 | 1 | 2 | 2 |
| 7 | 84 | 1 | 1 | 2 |
| 8 | 84 | 1 | 1 | 2 |
| 9 | 84 | 1 | 1 | 2 |
| 10 | 84 | 1 | 1 | 2 |
| 11 | 84 | 1 | 1 | 2 |
| 12 | 84 | 1 | 1 | 2 |
| 1 | 85 | 1 | 1 | 1 |
| 2 | 85 | 1 | 1 | 2 |
| 3 | 85 | 1 | 1 | 1 |
| 4 | 85 | 1 | 1 | 2 |
| 5 | 85 | 1 | 1 | 2 |
| 6 | 85 | 1 | 1 | 2 |
| 7 | 85 | 1 | 1 | 2 |
| 8 | 85 | 1 | 1 | 2 |
| 9 | 85 | 1 | 1 | 2 |

1 = Water Years 1982-1983 coefficients.
2 = Water Years 1986-1987 coefficients.

Table A-14 shows the percent difference between the computed loads and published USGS monthly loads for WY 1984-1985. The percent difference was computed as (published-computed)/published*100.

## TABLE A-14

## TERRAL GAGE
## PERCENT DIFFERENCE FROM USGS DATA
## (WATER YEARS 1984-1985)

| Month | Year | Cl | $SO_4$ | TDS |
|---|---|---|---|---|
| 10 | 83 | 0.1 | 3.6 | 0.1 |
| 11 | 83 | 0.2 | 2.0 | 0.2 |
| 12 | 83 | 0.3 | 0.8 | -0.2 |
| 1 | 84 | 0.4 | 0.3 | -0.1 |
| 2 | 84 | 0.5 | -0.3 | -0.2 |
| 3 | 84 | 0.3 | 1.3 | 0.1 |
| 4 | 84 | 0.3 | 1.3 | -0.1 |
| 5 | 84 | 0.3 | 0.2 | 0.0 |
| 6 | 84 | 0.5 | 0.1 | -0.3 |
| 7 | 84 | 0.4 | -0.6 | -0.1 |
| 8 | 84 | 0.3 | 0.7 | 0.0 |
| 9 | 84 | 0.4 | 0.6 | -0.1 |
| 10 | 84 | 0.2 | 1.7 | -0.1 |
| 11 | 84 | 0.1 | 2.4 | 0.1 |
| 12 | 84 | 0.3 | 2.1 | 0.2 |
| 1 | 85 | 0.0 | 3.6 | 0.0 |
| 2 | 85 | 0.1 | 2.6 | 0.3 |
| 3 | 85 | 0.1 | 3.6 | 0.1 |
| 4 | 85 | 0.2 | 3.1 | 0.3 |
| 5 | 85 | 0.2 | 2.9 | 0.3 |
| 6 | 85 | 0.2 | 3.0 | 0.2 |
| 7 | 85 | 0.4 | 0.9 | -0.1 |
| 8 | 85 | 0.3 | 0.9 | -0.1 |
| 9 | 85 | 0.4 | -0.1 | 0.3 |

Table A-15 shows the percent difference between the computed loads and published USGS monthly loads for WY 1974-1994. The percent difference was computed as (published-computed)/published*100.

**TABLE A-15**

**TERRAL GAGE**
**PERCENT DIFFERENCE FROM USGS DATA**
**(WATER YEARS 1974-1997)**

| Year | Cl | $SO_4$ | TDS |
|---|---|---|---|
| 1974 | 0.4 | 0.2 | 0.0 |
| 1975 | 1.1 | 0.6 | 0.7 |
| 1976 | -0.0 | 0.2 | 0.2 |
| 1977 | 0.2 | 0.2 | 0.4 |
| 1978 | -0.4 | 0.4 | -0.2 |
| 1979 | 0.4 | 1.7 | 0.5 |
| 1980 | 0.4 | 0.3 | 0.4 |
| 1981 | 0.4 | 0.4 | 0.4 |
| 1982 | 0.4 | 0.3 | 0.4 |
| 1983 | 0.3 | 0.2 | 0.4 |
| 1984 | 0.3 | 1.6 | 0.1 |
| 1985 | 0.2 | 2.6 | 0.2 |
| 1986 | 0.4 | 0.4 | 0.4 |
| 1987 | 0.4 | 0.4 | 0.3 |
| 1988 | 0.4 | 0.4 | 0.4 |
| 1989 | 0.4 | 0.3 | 0.4 |
| 1990 | 0.3 | 0.4 | 0.4 |
| 1991 | 0.4 | 0.4 | 0.4 |
| 1992 | 0.2 | 0.2 | -3.4 |
| 1993 | 0.4 | 0.4 | -4.4 |
| 1994 | -1.4 | -0.8 | -0.7 |
| 1995 | 0.3 | 0.3 | 0.3 |
| 1996 | 0.4 | 0.3 | 0.4 |
| 1997 | 0.4 | 0.3 | 0.4 |

## GAINESVILLE GAGE

Water quality data prior to WY 1980 were computed in a previous study. Flow and specific conductance data were available for WY 1980-1989. Regression coefficients were available for all years except WY 1984-1985. Rather than plot up the data and make a best guess curve from a specific conductance correlation with concentration, the WY 1983 and 1986 coefficients were both used to compute WY 1984-1985 concentrations. The coefficient that more closely reproduced the published USGS monthly loads was used. Table A-16 indicates which coefficient provided the closest monthly totals for each parameter.

## TABLE A-16

## GAINESVILLE GAGE
## COEFFICIENTS USED FOR WATER YEARS 1984-1985

| Month | Year | Cl | $SO_4$ | TDS |
|---|---|---|---|---|
| 10 | 83 | 1 | 2 | 1 |
| 11 | 83 | 1 | 2 | 1 |
| 12 | 83 | 1 | 1 | 1 |
| 1 | 84 | 2 | 1 | 2 |
| 2 | 84 | 2 | 2 | 2 |
| 3 | 84 | 1 | 2 | 1 |
| 4 | 84 | 1 | 2 | 1 |
| 5 | 84 | 1 | 1 | 1 |
| 6 | 84 | 2 | 2 | 2 |
| 7 | 84 | 2 | 2 | 2 |
| 8 | 84 | 2 | 1 | 2 |
| 9 | 84 | 2 | 1 | 2 |
| 10 | 84 | 1 | 2 | 1 |
| 11 | 84 | 1 | 2 | 1 |
| 12 | 84 | 1 | 2 | 1 |
| 1 | 85 | 1 | 2 | 1 |
| 2 | 85 | 1 | 2 | 1 |
| 3 | 85 | 1 | 2 | 1 |
| 4 | 85 | 1 | 2 | 1 |
| 5 | 85 | 1 | 2 | 1 |
| 6 | 85 | 1 | 2 | 1 |
| 7 | 85 | 1 | 2 | 1 |
| 8 | 85 | 2 | 1 | 1 |
| 9 | 85 | 1 | 1 | 1 |

1 = Water Year 1983 coefficients.
2 = Water Year 1986 coefficients.

Table A-17 shows the percent difference between the computed loads and the published USGS loads for WY 1984-1985. The percent difference was computed as (published-computed)/published*100.

## TABLE A-17

## GAINESVILLE GAGE
## PERCENT DIFFERENCE FROM USGS DATA
## (WATER YEARS 1984-1985)

| Month | Year | Cl | $SO_4$ | TDS |
|---|---|---|---|---|
| 10 | 83 | 0.0 | 0.1 | 0.0 |
| 11 | 83 | 0.0 | 0.1 | 0.0 |
| 12 | 83 | 0.1 | 0.1 | 0.0 |
| 1 | 84 | 0.1 | 0.1 | 0.0 |
| 2 | 84 | 0.1 | 0.2 | 0.0 |
| 3 | 84 | 0.1 | 0.2 | 0.0 |
| 4 | 84 | 0.1 | 0.2 | 0.0 |
| 5 | 84 | 0.1 | 0.3 | 0.1 |
| 6 | 84 | 0.1 | 0.2 | 0.0 |
| 7 | 84 | 0.2 | 0.3 | 0.1 |
| 8 | 84 | 0.3 | 0.5 | 0.1 |
| 9 | 84 | 0.4 | 0.8 | 0.2 |
| 10 | 84 | 0.1 | 0.3 | 0.1 |
| 11 | 84 | 0.2 | 0.3 | 0.1 |
| 12 | 84 | 0.1 | 0.1 | 0.0 |
| 1 | 85 | 0.1 | 0.1 | 0.0 |
| 2 | 85 | 0.1 | 0.1 | 0.0 |
| 3 | 85 | 0.0 | 0.1 | 0.0 |
| 4 | 85 | 0.1 | 0.1 | 0.0 |
| 5 | 85 | 0.0 | 0.1 | 0.0 |
| 6 | 85 | 0.0 | 0.1 | 0.0 |
| 7 | 85 | 0.1 | 0.2 | 0.0 |
| 8 | 85 | 0.1 | 0.2 | 0.0 |
| 9 | 85 | 0.1 | 0.1 | 0.0 |

Table A-18 shows the percent difference between the computed loads and published USGS loads for WY 1974-1989. The percent difference was computed as (published-computed)/published*100.

**TABLE A-18**

**GAINESVILLE GAGE**
**PERCENT DIFFERENCE FROM USGS DATA**
**(WATER YEARS 1974-1989)**

| Water Year | Flow | Cl | $SO_4$ | TDS |
|---|---|---|---|---|
| 1974 | 0 | -1.1 | -3.8 | -0.6 |
| 1975 | 0 | 0.9 | 1.6 | -1.9 |
| 1976 | 0 | 4.8 | 5.1 | 5 |
| 1977 | 0 | 6.3 | 6.1 | 2.7 |
| 1978 | 0 | 0.6 | 0.3 | 0.5 |
| 1979 | 0 | 0.5 | 0.4 | 0.3 |
| 1980 | 0 | 0.4 | 0.3 | 0.4 |
| 1981 | 0 | 0.3 | 0.5 | 0.4 |
| 1982 | 0 | 0.3 | 0.3 | 0.3 |
| 1983 | 0 | 0.4 | 0.4 | 0.4 |
| 1984 | 0 | 0.4 | 1.6 | 0.2 |
| 1985 | 0 | -1.4 | 2.4 | -0.2 |
| 1986 | 0 | 0.4 | 0.4 | 0.4 |
| 1987 | 0 | 0.3 | 0.4 | 0.4 |
| 1988 | 0 | 0.4 | 0.3 | 0.4 |
| 1989 | 0 | 0.4 | 0.4 | 0.4 |

For WY 1995-1998, flow and specific conductance data were published without monthly totals or regression coefficients. A correlation study was made relating specific conductance to concentrations. Concentrations were computed for this period using this correlation.

**DENISON GAGE**

Water quality data for WY 1962-1972 were computed during a previous study. These data were used in this study. Regression coefficients were not available for WY 1973. Water Year 1974 regression coefficients were used to calculate WY 1973 loads by adjusting the monthly totals to the published monthly totals. Flow and specific conductance data, regression coefficients, and monthly totals were available for WY 1974-1989.

Daily flow and specific conductance data were available for February 1997-September 1998, but no monthly totals or regression coefficients were available. Regression coefficients for WY 1989 were used to compute the concentrations for this period. The gage was discontinued until February 1997.

Table A-19 shows the final percent difference between computed loads and published USGS loads for WY 1974-1989.

**TABLE A-19**
**DENISON GAGE**
**FINAL PERCENT DIFFERENCE FROM USGS DATA**

| Year | Flow | Cl | $SO_4$ | TDS |
|---|---|---|---|---|
| 1973 | 0.0 | 0.1 | 3.0 | 0.1 |
| 1974 | 0.0 | 0.2 | 0.0 | 0.1 |
| 1975 | 0.0 | 0.1 | 0.1 | 0.1 |
| 1976 | 0.0 | 0.1 | 0.0 | 0.1 |
| 1977 | 0.0 | 0.2 | 0.5 | 0.4 |
| 1978 | 0.0 | 0.1 | 0.5 | 0.5 |
| 1979 | 0.0 | 1.0 | 0.4 | 0.2 |
| 1980 | 0.0 | 0.4 | 0.5 | 0.4 |
| 1981 | 0.0 | 0.4 | 0.4 | 0.4 |
| 1982 | 0.3 | 0.1 | 0.0 | 0.1 |
| 1983 | 0.0 | 0.3 | 0.4 | 0.3 |
| 1984 | 0.0 | 0.3 | 1.1 | 0.2 |
| 1985 | 0.0 | 1.0 | 1.5 | 0.8 |
| 1986 | 0.0 | 0.5 | 0.6 | 0.0 |
| 1987 | 0.0 | 1.8 | 0.4 | 0.1 |
| 1988 | 0.0 | 0.3 | 0.4 | 0.3 |
| 1989 | 0.0 | 0.3 | 0.3 | 0.4 |

## HOSSTON, LOUISIANA, GAGE

Daily data were available for October 1970 through August 1986. During this period, 94% of the water quality data were available while only 16% of the daily flows were available. Both flow and concentration data were available only 10% of the time. Therefore, these data were not used due to the scarcity of both flow and concentration data.

## USGS REGRESSION COEFFICIENT TABLES

The following pages contain Tables A-20 through A-24, which are the USGS regression coefficient tables for Truscott (M.F) - Seymour gages (WY 1970-1979); the Mabelle and Terral gages (WY 1970-1979); the Gainesville and Denison gages (WY 1970-1979); the Paducah – Seymour gages (WY 1980-1998); and the Mabelle – Denison gages (WY 1980-1998), respectively.

**TABLE A-20**
**USGS REGRESSION COFFICIENTS – TRUSCOTT (M.F.) – SEYMOUR GAGES (WATER YEARS 1970-1979)**

Concentration = C1*Cond+C2 up to Limit 1
= C3*Cond+C4 (Limit 1<Cond>Limit 2)
= C5*Cond+C6 (Limit 2<Cond>Limit 3)
= C7*Cond+C8 (Limit 3<Cond>Limit 4)

| Location | Year | C1 | C2 | Limit 1 | C3 | C4 | Limit 2 | C5 | C6 | Limit 3 | Parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Truscott (M.F.) | 1971 | 0.4337 | -290 | 99999 | | | | | | | Chloride |
| | -1975 | 0.5000 | 0 | 1000 | 0.5700 | 0 | 2000 | 0.6200 | 0 | 99999 | Sulfate |
| | | 0.6500 | 0 | 10000 | 0.7156 | -544 | 99999 | | | | TDS |
| | 1976 | 0.4182 | 0 | 1700 | 0.4158 | -197 | 99999 | | | | Chloride |
| | | 0.1596 | 0 | 7000 | 0.0510 | 740 | 9000 | 0.1333 | 0 | 99999 | Sulfate |
| | | 0.6500 | 0 | 10000 | 0.7156 | -544 | 99999 | | | | TDS |
| Truscott (N.F.) | 1975 | 0.2222 | -100 | 5000 | 0.3100 | -500 | 12500 | 0.4082 | -1760 | 99999 | Chloride |
| | | 0.1596 | 0 | 7000 | 0.0510 | 740 | 9000 | 0.1333 | 0 | 99999 | Sulfate |
| | | 0.6190 | 0 | 10000 | 0.7169 | -980 | 99999 | | | | TDS |
| | 1978 | 0.2749 | 0 | 15000 | 0.4081 | -2116 | 99999 | | | | Chloride |
| | | 0.1492 | 0 | 6000 | 0.1143 | 200 | 99999 | | | | Sulfate |
| | | 0.6190 | 0 | 10000 | 0.7189 | -980 | 99999 | | | | TDS |
| | 1979 | 0.2749 | 0 | 15000 | 0.4081 | -2116 | 99999 | | | | Chloride |
| | | 0.1294 | 0 | 99999 | | | | | | | Sulfate |
| | | 0.6311 | 0 | 15000 | 0.9131 | -4739 | 99999 | | | | TDS |
| Guthrie (S.F.) | 1975 | 0.5428 | -852 | 99999 | | | | | | | Chloride |
| | | 0.6150 | 0 | 10000 | 0.6260 | 0 | 20000 | 0.6280 | 0 | 99999 | Sulfate |
| | | 0.6480 | 0 | 30000 | 0.6962 | -1380 | 99999 | | | | TDS |
| | 1976 | 0.4862 | 0 | 15000 | 0.5428 | -852 | 99999 | | | | Chloride |
| | | 0.6150 | 0 | 10000 | 0.6260 | 0 | 20000 | 0.6270 | 0 | 99999 | Sulfate |
| | | 0.6295 | 0 | 20000 | 0.7422 | -2097 | 99999 | | | | TDS |
| Seymour | 1978 | 0.1381 | 0 | 560 | 0.4356 | -168 | 5000 | 0.4704 | -266 | 99999 | Chloride |
| | | 0.1366 | 105 | 10000 | 0.1151 | 213 | 99999 | | | | Sulfate |
| | | 0.6000 | 0 | 8000 | 0.7226 | -972 | 99999 | | | | TDS |
| | 1979 | 0.2591 | 0 | 10000 | 0.3356 | -628 | 99999 | | | | Chloride |
| | | 0.1366 | 105 | 10000 | 0.1151 | 213 | 99999 | | | | Sulfate |
| | | 0.6637 | 0 | 99999 | | | | | | | TDS |

**TABLE A-21**

**USGS REGRESSION COFFICIENTS – MABELLE AND TERRAL GAGES (WATER YEARS 1970-1979)**

| Location | Year | C1 | C2 | Limit 1 | C3 | C4 | Limit 2 | C5 | C6 | Limit 3 | Parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mabelle | 1978 | 0.1456 | 0 | 1000 | 0.2688 | -122 | 5000 | 0.3340 | -444 | 99999 | Chloride |
| | | 0.0927 | 0 | 1000 | 0.1493 | -53 | 99999 | | | | Sulfate |
| | | 0.5206 | 0 | 1000 | 0.6448 | -125 | 5250 | 0.7764 | -815 | 99999 | TDS |
| | 1979 | 0.2423 | 0 | 5200 | 0.3848 | -775 | 99999 | | | | Chloride |
| | | 0.1377 | 0 | 99999 | | | | | | | Sulfate |
| | | 0.6137 | 0 | 5200 | 0.8850 | -1510 | 99999 | | | | TDS |
| Terral | 1974 | 0.2541 | -75 | 99999 | | | | | | | Chloride |
| | | 0.1238 | -37 | 99999 | | | | | | | Sulfate |
| | | 0.6111 | -67 | 99999 | | | | | | | TDS |
| | 1975 | 0.2467 | -14 | 99999 | | | | | | | Chloride |
| | | 0.1417 | -44 | 99999 | | | | | | | Sulfate |
| | | 0.6162 | -47 | 99999 | | | | | | | TDS |
| | 1976 | 0.1528 | 0 | 500 | 0.2680 | -77 | 99999 | | | | Chloride |
| | | 0.0757 | 0 | 600 | 0.1250 | -12 | 99999 | | | | Sulfate |
| | | 0.5470 | 0 | 1000 | 0.6162 | -47 | 99999 | | | | TDS |
| | 1977 | 0.1528 | 0 | 500 | 0.2680 | -77 | 99999 | | | | Chloride |
| | | 0.0757 | 0 | 600 | 0.1250 | -12 | 99999 | | | | Sulfate |
| | | 0.5470 | 0 | 1000 | 0.6162 | -47 | 99999 | | | | TDS |
| | 1978 | 0.1528 | 0 | 500 | 0.2595 | -58 | 99999 | | | | Chloride |
| | | 0.0757 | 0 | 600 | 0.1440 | -38 | 99999 | | | | Sulfate |
| | | 0.5470 | 0 | 1000 | 0.6162 | -47 | 99999 | | | | TDS |
| | 1979 | 0.1986 | 0 | 2500 | 0.2759 | -141 | 99999 | | | | Chloride |
| | | 0.1230 | 0 | 2500 | 0.1276 | -13 | 99999 | | | | Sulfate |
| | | 0.5705 | 0 | 2500 | 0.6425 | -157 | 99999 | | | | TDS |

**TABLE A-22**

**USGS REGRESSION COFFICIENTS – GAINESVILLE AND DENISON GAGES (WATER YEARS 1970-1979)**

| Location | Year | C1 | C2 | Limit 1 | C3 | C4 | Limit 2 | C5 | C6 | Limit 3 | Parameter |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gainesville | 1974 | 0.2366 | -47 | 3400 | 0.3010 | -262 | 99999 | | | | Chloride |
| | | 0.0870 | 0 | 2000 | 0.1304 | -91 | 99999 | | | | Sulfate |
| | | 0.5319 | 0 | 1600 | 0.6325 | -164 | 99999 | | | | T.D.S. |
| | 1975 | 0.2600 | -90 | 99999 | | | | | | | Chloride |
| | | 0.1018 | 0 | 2000 | 0.1525 | -91 | 99999 | | | | Sulfate |
| | | 0.6404 | -78 | 99999 | | | | | | | T.D.S. |
| | 1976 | 0.0683 | 0 | 500 | 0.2650 | -72 | 99999 | | | | Chloride |
| | | 0.0866 | 0 | 1000 | 0.1194 | -30 | 99999 | | | | Sulfate |
| | | 0.5581 | 0 | 1000 | 0.6204 | -78 | 99999 | | | | T.D.S. |
| | 1977 | 0.0683 | 0 | 500 | 0.2626 | -96 | 99999 | | | | Chloride |
| | | 0.0866 | 0 | 1000 | 0.1194 | -30 | 99999 | | | | Sulfate |
| | | 0.5581 | 0 | 1000 | 0.6276 | -41 | 99999 | | | | T.D.S. |
| | 1978 | 0.0683 | 0 | 500 | 0.2650 | -72 | 99999 | | | | Chloride |
| | | 0.0866 | 0 | 1000 | 0.1431 | -53 | 99999 | | | | Sulfate |
| | | 0.5581 | 0 | 1000 | 0.6204 | -78 | 99999 | | | | T.D.S. |
| | 1979 | 0.2464 | 0 | 99999 | | | | | | | Chloride |
| | | 0.1229 | 0 | 99999 | | | | | | | Sulfate |
| | | 0.5827 | 0 | 3000 | 0.6277 | -109 | 99999 | | | | T.D.S. |
| Denison | 1973 | 0.2403 | -65 | 99999 | | | | | | | Chloride |
| | -1975 | 0.1096 | -5 | 99999 | | | | | | | Sulfate |
| | | 0.5577 | 7 | 99999 | | | | | | | T.D.S. |
| | 1976 | 0.1830 | 0 | 1100 | 0.2083 | -28 | 99999 | | | | Chloride |
| | | 0.1200 | 0 | 1000 | 0.1680 | -48 | 99999 | | | | Sulfate |
| | | 0.5662 | 0 | 1200 | 0.6028 | -41 | 99999 | | | | T.D.S. |
| | 1977 | 0.1830 | 0 | 1100 | 0.2083 | -28 | 1700 | 0.2605 | -114 | 99999 | Chloride |
| | | 0.1200 | 0 | 1000 | 0.1530 | -33 | 99999 | | | | Sulfate |
| | | 0.5662 | 0 | 1200 | 0.5886 | -23 | 99999 | | | | T.D.S. |
| | 1978 | 0.1830 | 0 | 1100 | 0.2067 | -25 | 99999 | | | | Chloride |
| | | 0.1200 | 0 | 1000 | 0.1693 | -47 | 99999 | | | | Sulfate |
| | | 0.5662 | 0 | 1200 | 0.5886 | -23 | 99999 | | | | T.D.S. |
| | 1979 | 0.1940 | 0 | 99999 | | | | | | | Chloride |
| | | 0.1716 | -65 | 99999 | | | | | | | Sulfate |
| | | 0.5650 | 0 | 1700 | 0.5794 | 14 | 99999 | | | | T.D.S. |

## TABLE A-23

## USGS REGRESSION COFFICIENTS – PADUCAH – SEYMOUR GAGES (WATER YEARS 1980-1998)

CONC = C1*COND + C2*COND*COND

| Location | Water Year | Chloride | | Sulfate | | TDS | |
|---|---|---|---|---|---|---|---|
| | | C1 | C2 | C1 | C2 | C1 | C2 |
| Paducah | 1996-1997 | 0.2152 | 0.000003500 | 0.1679 | -0.000002900 | 0.6871 | -0.000002600 |
| | 1998 | 0.2468 | 0.000002884 | 0.1892 | -0.000003629 | 0.6863 | -0.000001122 |
| Guthrie | 1995-1997 | 0.2260 | 0.000002000 | 0.3997 | -0.000001730 | 0.9335 | -0.000020500 |
| (M.F.) | 1998 | 0.2331 | 0.000001370 | 0.3888 | -0.000016440 | 0.9414 | -0.000021240 |
| Truscott | 1980-1981 | 0.2203 | 0.000004135 | 0.1492 | -0.000001106 | 0.5908 | 0.000004181 |
| (N.F.) | 1982-1983 | 0.2269 | 0.000003893 | 0.1491 | -0.000001027 | 0.6018 | 0.000003995 |
| | 1984-1985 | Combination of 1982-1983 & 1986-1987 coefficients | | | | | |
| | 1986-1987 | 0.2340 | 0.000003400 | 0.1459 | -0.000000800 | 0.6325 | 0.000002500 |
| | 1988-1989 | 0.2428 | 0.000003100 | 0.1597 | -0.000001200 | 0.6430 | 0.000002000 |
| | 1990-1991 | 0.2355 | 0.000003200 | 0.1676 | -0.000001400 | 0.6440 | 0.000002100 |
| | 1992 | 0.2108 | 0.000004400 | 0.2000 | -0.000003300 | 0.6118 | 0.000004100 |
| | 1995 | 0.1913 | 0.000005500 | 0.2178 | -0.000004300 | 0.6030 | 0.000005200 |
| | 1996-1997 | 0.1916 | 0.000005500 | 0.2205 | -0.000004500 | 0.6293 | 0.000002500 |
| | 1998 | 0.2016 | 0.000004964 | 0.2171 | -0.000004211 | 0.6466 | 0.000001513 |
| Guthrie | 1985-1987 | 0.2876 | 0.000001500 | 0.1163 | -0.000000700 | 0.6243 | 0.000001700 |
| @LFD | 1988-1989 | 0..2763 | 0.000001800 | 0.1158 | -0.000000700 | 0.6131 | 0.000001900 |
| | 1990-1991 | 0.2820 | 0.000001500 | 0.1211 | -0.000000900 | 0.6192 | 0.000001600 |
| | 1992-1993 | 0.2636 | 0.000002100 | 0.1208 | -0.000001000 | 0.6239 | 0.000001400 |
| | 1994-1995 | 0.2584 | 0.000002300 | 0.1227 | -0.000001000 | 0.6231 | 0.000001500 |
| | 1996-1997 | 0.2691 | 0.000001800 | 0.1263 | -0.000001200 | 0.6226 | 0.000001100 |
| | 1998 | 0.2254 | 0.000003285 | 0.1163 | -0.000001008 | 0.5477 | 0.000003471 |
| Guthrie | 1986-1987 | 0.2876 | 0.000001500 | 0.1163 | -0.000000700 | 0.6243 | 0.000001700 |
| Below LFD | 1988-1989 | 0.3266 | 0.000000500 | 0.1158 | -0.000000500 | 0.6986 | 0.000001500 |
| Benjamin | 1988-1989 | 0.2651 | 0.000002200 | 0.1855 | -0.000002700 | 0.6887 | |
| | 1990-1991 | 0.2110 | 0.000004400 | 0.2134 | -0.000003600 | 0.6446 | 0.000002200 |
| | 1992-1993 | 0.1878 | 0.000005000 | 0.2269 | -0.000003900 | 0.6581 | 0.000001600 |
| | 1994-1995 | 0.1913 | 0.000004700 | 0.2627 | -0.000005300 | 0.6702 | 0.000001100 |
| | 1996-1997 | 0.1907 | 0.000004600 | 0.2786 | -0.000006200 | 0.7126 | 0.000001600 |
| | 1998 | 0.1861 | 0.000005048 | 0.2992 | -0.000007466 | 0.7336 | -0.000002850 |
| Seymour | 1997 | 0.1633 | 0.000013010 | 0.1418 | 0.000001899 | 0.5390 | 0.000014320 |
| | 1998 | 0.1975 | 0.000006117 | 0.2379 | -0.000005739 | 0.6715 | 0.000000828 |

**TABLE A-24**

**USGS REGRESSION COFFICIENTS – MABELLE – DENISON GAGES (WATER YEARS 1980-1998)**

| Location | Water Year | Chloride | | Sulfate | | TDS | |
|---|---|---|---|---|---|---|---|
| | | C1 | C2 | C1 | C2 | C1 | C2 |
| Mabelle | 1980-1981 | 0.2020 | 0.000008120 | 0.1308 | 0.000001165 | 0.5828 | 0.000005842 |
| | 1982-1983 | 0.1945 | 0.000009857 | 0.1432 | -0.000001283 | 0.5803 | 0.000006710 |
| | 1984-1985 | Combination of 1982-1983 & 1986-1987 coefficients | | | | | |
| | 1986-1987 | 0.1901 | 0.000010800 | 0.1331 | 0.000000300 | 0.5682 | 0.000008800 |
| | 1988-1989 | 0.1913 | 0.000010500 | 0.1453 | -0.000001800 | 0.5715 | 0.000007700 |
| | 1990-1991 | 0.1847 | 0.000011100 | 0.1538 | -0.000002500 | 0.5586 | 0.000010300 |
| | 1992-1993 | 0.1727 | 0.000012700 | 0.1730 | -0.000005400 | 0.5619 | 0.000009800 |
| | 1995 | 0.1844 | 0.000009700 | 0.1762 | -0.000005500 | 0.6159 | 0.000000200 |
| | 1996-1997 | 0.1842 | 0.000008800 | 0.1851 | -0.000005900 | 0.5837 | 0.000005800 |
| | 1998 | 0.1515 | 0.000015330 | 0.2233 | -0.000013020 | 0.5886 | 0.000005406 |
| Wichita | 1982-1983 | 0.1855 | 0.000015630 | 0.0980 | 0.000001708 | 0.5090 | 0.000019530 |
| Falls | 1984 | 0.2299 | 0.000006200 | 0.0900 | 0.000003100 | 0.5513 | 0.000008900 |
| | 1985 | 0.1855 | 0.000015630 | 0.0980 | 0.000001708 | 0.5513 | 0.000008900 |
| | 1986-1987 | 0.2299 | 0.000006200 | 0.0900 | 0.000003100 | 0.5513 | 0.000008900 |
| | 1988-1989 | 0.2322 | 0.000004700 | 0.1054 | 0.000000900 | 0.5768 | 0.000006700 |
| Terral | 1980-1981 | 0.2007 | 0.000008149 | 0.1415 | -0.000002055 | 0.5838 | 0.000005401 |
| | 1982-1983 | 0.1983 | 0.000007747 | 0.1290 | -0.000000504 | 0.5875 | 0.000004578 |
| | 1984-1985 | Combination of 1982-1983 & 1986-1987 coefficients | | | | | |
| | 1986-1987 | 0.1796 | 0.000010300 | 0.1283 | -0.000000700 | 0.5851 | 0.000005600 |
| | 1988-1989 | 0.1891 | 0.000010400 | 0.1386 | -0.000002100 | 0.5685 | 0.000007800 |
| | 1990-1991 | 0.1880 | 0.000010200 | 0.1403 | -0.000001700 | 0.5525 | 0.000010200 |
| | 1992-1993 | 0.1648 | 0.000012700 | 0.1247 | 0.000003800 | 0.5525 | 0.000010200 |
| | 1994-1995 | 0.1690 | 0.000012600 | 0.1400 | 0.000000100 | 0.5139 | 0.000017900 |
| | 1996-1997 | 0.1720 | 0.000011300 | 0.1275 | 0.000004100 | 0.5391 | 0.000013400 |
| Gainesville | 1980-1981 | 0.2279 | 0.000003600 | 0.1157 | 0.000001500 | 0.5757 | 0.000005600 |
| | 1982-1983 | 0.2336 | 0.000002900 | 0.1064 | 0.000002900 | 0.5751 | 0.000005600 |
| | 1984-1985 | Combination of 1982-1983 & 1986-1987 coefficients | | | | | |
| | 1986-1987 | 0.2167 | 0.000006200 | 0.1155 | 0.000000900 | 0.5643 | 0.000007600 |
| | 1988-1989 | 0.2154 | 0.000007000 | 0.1182 | 0.000000500 | 0.5691 | 0.000007500 |
| Denison | 1980-1981 | 0.1804 | 0.000008782 | 0.0947 | 0.000021200 | 0.5203 | 0.000031980 |
| | 1982-1983 | 0.1833 | 0.000008430 | 0.0855 | 0.000025710 | 0.5289 | 0.000027820 |
| | 1984 | 0.1732 | 0.000013610 | 0.1165 | 0.000010260 | 0.5409 | 0.000021990 |
| | 1985 | 0.1803 | 0.000010240 | 0.1278 | 0.000004768 | 0.5542 | 0.000015570 |
| | 1986 | 0.1802 | 0.000010660 | 0.1186 | 0.000009096 | 0.5485 | 0.000018160 |
| | 1987 | 0.1517 | 0.000026880 | 0.1083 | 0.000045660 | 0.5514 | 0.000017280 |
| | 1988-1989 | 0.1324 | 0.000038100 | 0.1300 | 0.000003100 | 0.5571 | 0.000012500 |

# APPENDIX B

# SYNTHESIZED DATA

# TABLE OF CONTENTS



## LIST OF TABLES

## INTRODUCTION

The following paragraphs contain additional information pertaining to the development of synthesized data at the low flow dams, Truscott, and Mabelle gages.

## AREA VII

The Paducah gage located near Area VII was in operation for water years (WY) 1962-1982 and 1995-1998. The ratio of the flows for Paducah and Truscott (N.F.) for those periods was .39. This value was used to synthesize the flows for Area VII for WY 1983-1994. Table B-1 shows the supporting data.

**TABLE B-1**

**AREA VII SUPPORTING DATA**

| Water Years | Number of Days | Gages | | | | Ratio |
|---|---|---|---|---|---|---|
| | | Paducah | | Truscott (N.F.) | | |
| | | Flow | Total Volume | Flow | Total Volume | |
| 62-70 | 3,286 | 17.00 | 55,862.0 | 63.60 | 208,989.6 | 0.27 |
| 71-82 | 4,382 | 26.30 | 115,246.6 | 54.30 | 237,942.6 | 0.48 |
| 95-98 | 1,460 | 40.95 | 59,787.0 | 98.10 | 143,226.0 | 0.42 |
| **Totals** | | | 230,895.6 | | 590,158.2 | 0.39 |

A flow/concentration correlation study was made and the following points were used to define a straight line on a log-log plot for the Cl and Sul concentrations. A (NaCl+CaSul)/TDS factor of .97 was used to compute the TDS concentrations.

## AREA VIII

For WY 1976-1984, flows were computed using a flow vs. flow correlation curve of Guthrie vs. Benjamin gages. An analysis of the Guthrie gage for WY 1971-1976 showed that the minimum flow was 2 cfs. A minimum 2-cfs flow was allowed in the synthesized flows. Using synthesized Guthrie flows, water quality data were computed from flow vs. Cl concentration and flow vs. Sul concentration curves. A comparison of the flow and Cl load at Guthrie (Area VIII) and Benjamin for the periods before and after the synthesized period are shown in Table B-2.

The flow ratios for the synthesized period fit well between the ratios for the gaged periods. The Cl load ratios for the synthesized data are considerably higher than the gaged periods. This can be explained by the fact that the average flows for the synthesized period at Benjamin are considerably lower than the average flow for the gaged periods. This is an indication that there is a Cl load being stored in the alluvium during this time period. This also explains why the periods of higher flow at Benjamin have somewhat higher Cl loads. The TDS concentrations were computed using 0.98 as the ($NaCl+CaSO_4$)/TDS factor.

**TABLE B-2**

**COMPARISON OF FLOW AND CL LOAD AT GUTHRIE (AREA VIII) AND BENJAMIN**

| Water Years | Average Flow | | Flow Ratio (%) | Average CL Load | | Load Ratio (%) |
|---|---|---|---|---|---|---|
| | Guthrie/Area VIII | Benjamin | | Guthrie/Area VIII | Benjamin | |
| 1971-1976 | 5.25 | 56.02 | 9 | 153 | 287 | 53 |
| 1977-1984 | 5.48 | 30.41 | 18 | 168 | 201 | 84 |
| 1985-1986 | 12.12 | 42.52 | 29 | 152 | 260 | 58 |

## AREA X

To determine the best method of synthesizing the flows for Area X, correlation curves were plotted using the Truscott (M.F.) and Guthrie gages vs. Truscott (N.F.). This plot looked like a shotgun pattern. The same plot was made by lagging the upstream flows by one day with the same results. A ratio of the Area X flows from the original study, WY 1962-1970, to the Truscott (N.F.) gage was made along with similar ratios using the Truscott (M.F.) and the Guthrie gages. The results of these computations are shown in Table B-3 with the drainage area ratio.

**TABLE B-3**

**RATIO OF TRUSCOTT GAGE (NORTH FORK)**

| Original Study WY 1962-1970 | Truscott Gage North Fork WY 1971-1976 | Guthrie Gage Middle Fork WY 1995-1998 | Drainage Area Ratio |
|---|---|---|---|
| 0.13 | 0.17 | 0.07 | 0.06 |

The Guthrie gage data had some higher flows missing in 1995 that would have made the ratio a little larger. The Truscott gage is downstream from the low flow dam location. It was decided to use the original study value of 0.13 with a minimum flow of 2.4 cfs. This was used because the source area flows are spring fed and very seldom get below this flow. Flow vs. concentration correlation plots were made for the same three periods for comparison. The original correlation was chosen to compute the Cl and $SO_4$ concentrations. For the Truscott (M.F.) and Guthrie gages, the $(NaCl+CaSO_4)/TDS$ factor used to compute the TDS concentrations was 0.97. For June-September 1994, flows were available but no specific conductance data were available. For this period, a flow-conductance relationship was used to compute specific conductance. There was a very good correlation between conductance and concentrations for this period; therefore, concentrations were computed based on these correlations. Table B-4 shows the ratio of the final loads computed vs. the Truscott (N.F.) loads for WY 1977-1994. For a comparison, the same data using the Truscott (M.F) and Guthrie gages are shown.

## TABLE B-4

## RATIO OF FINAL LOADS COMPUTED GUTHRIE GAGE (MIDDLE FORK)

| Parameter | Truscott Gage North Fork WY 1971-1976 | Synthesized Data WY 1977-1994 | Guthrie Gage Middle Fork WY 1995-1998 |
|---|---|---|---|
| Chloride | 0.21 | 0.17 | 0.15 |
| Sulfate | 0.28 | 0.26 | 0.17 |
| TDS | 0.25 | 0.20 | 0.16 |

### TRUSCOTT GAGE

Flow/concentration plots were made for several periods during WY 1990-1994 to determine the concentrations for the January-August 1990 and the July 1992-September 1994 periods. It was ultimately decided to give more weight to the periods near the time frame to be synthesized. A $(NaCl+CaSO_4)/TDS$ ratio of .95 was used to compute the TDS concentrations.

### MABELLE GAGE

The Seymour gage is the only gage whose data were modified prior to WY 1970. The modified data at the Seymour gage compared well with the USGS recorded flows for the period April 1, 1964, through May 31, 1966. This period of record was recomputed. There were no water quality data available for this period. Flow/concentration correlation curves for chloride and sulfate were computed. Correlation curves were plotted for the 3-month period prior to and flowing the missing data as well as the total period prior to (June 1966-September 1970) and following the missing data. A log-log plot of each data set was made and a straight line drawn to approximate a best fit. The period prior to the missing period plotted higher than the period following the missing period. Therefore, three lines were used as a transition from one to the other. This method was used for both Cl and $SO_4$. A program was written to compute the daily values. Two points were used to describe the equation needed to fill in the missing data for each parameter. Several attempts were made in determining the final equations. Long-term average loads were computed after using each set of equations and compared to the Mabelle gage. The sum of the Truscott and Benjamin gages was also used as a guideline. The data for the missing periods were divided up into three smaller periods. Table B-5 shows the final data used.

**TABLE B-5**

**MABELLE GAGE**
**LOG-LOG CURVE DEFINITION POINTS**

| Date | Cl1 | QC1 | Cl2 | QC2 | Sul1 | QS1 | Sul2 | QS2 |
|---|---|---|---|---|---|---|---|---|
| 4/1/64-12/31/64 | 10000 | 7.5 | 200 | 10000 | 8000 | 1 | 150 | 10000 |
| 1/1/65- 7/31/65 | 10000 | 7.5 | 200 | 10000 | 5100 | 1 | 150 | 10000 |
| 8/1/65- 5/31/66 | 10000 | 1.0 | 200 | 10000 | 3000 | 1 | 150 | 10000 |

The period June 1993 through September 1994 had no water quality data available. Flow/concentration correlation plots were made using the WY 1992-1996 data at the Mabelle gage. This period produced a better correlation and also surrounded the period for which the data were to be synthesized. From these plots, best fit lines were drawn and concentrations computed. A (NaCl+$CaSO_4$)/TDS ratio of 0.95 was used to compute the TDS concentrations.

# APPENDIX C

# MODIFIED CONCENTRATION/ DURATION CURVE DETAILS

## TABLE OF CONTENTS



## LIST OF TABLES

## GENERAL

This appendix provides more detailed information relating to the derivation of modified duration curves for the gages. Table C-1 lists average Cl loads and Cl load reductions used in this study. Reductions in flow are listed as pumped flows.

### TABLE C-1

### DATA SUMMARY OF AVERAGE CL LOADS AND CL LOAD REDUCTIONS

| Location | Period Of Record | Type of Data | Flow (cfs) | Loads (T/D) | | |
|---|---|---|---|---|---|---|
| | | | | Cl | $SO_4$ | TDS |
| Area VII | WY 1962-1998 | Gaged/Syn | 26.98 | 244 | 87 | 539 |
| | | Pumped | 10.15 | 195 | 63 | 419 |
| | WY 1962-4/87 | Gaged/Syn | 23.42 | 219 | 73 | 474 |
| | | Pumped | 9.35 | 182 | 56 | 387 |
| | 5/87- WY 1998 | Gaged/Syn | 34.96 | 300 | 119 | 684 |
| | | Pumped | 11.96 | 223 | 79 | 490 |
| Area VIII | WY 1962-1998 | Gaged/Syn | 10.18 | 189 | 49 | 380 |
| | | Pumped | 5.56 | 165 | 42 | 332 |
| | WY 1962-4/87 | Gaged/Syn | 10.28 | 162 | 40 | 324 |
| | | Pumped | 4.75 | 144 | 35 | 286 |
| | 5/87-WY 1998 | Gaged/Nat | 9.80 | 243 | 67 | 496 |
| | | Pumped/Gaged | 6.20 | 185 | 49 | 375 |
| Area X | WY 1962-1998 | Gaged/Syn | 8.25 | 58 | 43 | 161 |
| | | Pumped | 4.84 | 49 | 36 | 137 |
| | WY 1962-4/87 | Gaged/Syn | 7.59 | 56 | 39 | 155 |
| | | Pumped | 4.70 | 49 | 34 | 135 |
| | 5/87-WY 1998 | Gaged/Syn | 9.73 | 61 | 51 | 177 |
| | | Pumped | 5.14 | 50 | 41 | 143 |
| Benjamin | WY 1962-4/87 | Gaged | 40.42 | 233 | 117 | 554 |
| | 5/87-WY 1998 | Gaged | 47.77 | 127 | 107 | 363 |
| Truscott | WY 1962-4/87 | Gaged/Syn | 60.89 | 289 | 145 | 698 |
| | 5/87-WY 1998 | Gaged/Syn | 80.49 | 364 | 215 | 912 |
| Mabelle | WY 1962-4/87 | Gaged/Syn | 142.07 | 458 | 267 | 1175 |
| | 5/87-WY 1998 | Gaged/Syn | 216.54 | 581 | 376 | 1536 |
| Wichita Falls | WY 1962-4/87 | Gaged/Syn | 242.40 | 557 | 220 | 1358 |
| | 5/87-WY 1998 | Gaged | 230.20 | 515 | 249 | 1261 |
| Terral | WY 1962-1998 | Gaged | 2541.74 | 3750 | 2191 | 10017 |
| | WY 1962-4/87 | Gaged | 1948.70 | 3199 | 1741 | 8356 |
| | 5/87-WY 1998 | Gaged | 3997.54 | 5100 | 3295 | 14097 |
| Gainesville | WY 1962-1998 | Gaged | 3152.90 | 4175 | 2355 | 11025 |
| | WY 1962-4/87 | Gaged | 2621.00 | 3598 | 1768 | 9117 |
| | 5/87-WY 1998 | Gaged | 5272.00 | 6475 | 4696 | 18626 |
| Denison | WY 1962-1998 | Gaged | 7777.00 | 6441 | 4295 | 18898 |
| | WY 1962-4/87 | Gaged | 5396.00 | 4198 | 2740 | 12318 |
| | 5/87-WY 1998 | Gaged | 8451.00 | 6969 | 4820 | 20716 |

SYN = Synthesized Data

**BENJAMIN GAGE**

There was only one modified condition for the Benjamin gage. The modified condition was with Area VIII in operation. Table C-2 shows the percentages used to modify the gage data.

**TABLE C-2**

**PERCENTAGES USED TO MODIFY GAGE DATA**

| Final Type Flow | Plan | Period | Factors Used | | |
|---|---|---|---|---|---|
| | | | Cl | $SO_4$ | TDS |
| Modified | W/8 Only | Oct 61 - Apr 87 | 0.618 | 0.299 | 0.516 |
| Natural | | May 87 - Sep 98 | 2.440 | 1.470 | 2.040 |

**TRUSCOTT GAGE**

There are two source areas above this gage, Area VII and Area X. Therefore, any reference to Area VIII is for identification only. Three modified conditions existed for this gage. Table C-3 shows the factors used to modify the gage data. This data covers the entire study period.

**TABLE C-3**

**FACTORS USED TO MODIFY GAGE DATA**

| Plan | Factors Used | | |
|---|---|---|---|
| | Cl | $SO_4$ | TDS |
| W/7 & 8 | 0.376 | 0.623 | 0.452 |
| W/8 & 10 | 0.843 | 0.784 | 0.821 |
| W/7, 8 & 10 | 0.219 | 0.389 | 0.272 |

## MABELLE GAGE/LAKE KEMP

The Mabelle gage is the outflow gage for Lake Kemp and therefore reflects the daily concentrations in Lake Kemp. Natural and modified concentration data were derived by applying factors to the gaged data. Table C-4 shows the factors used to modify the gage data to obtain natural conditions after April 1987 and the modified data for each modified condition. TDS concentrations were computed using a factor of .97 or TDS = (1.6*Cl+1.4*Sul)/.97.

**TABLE C-4**

**FACTORS USED TO MODIFY GAGE DATA TO OBTAIN NATURAL CONDITIONS**

| Type of Flow | Plan | Factors Used | | | |
|---|---|---|---|---|---|
| | | Cl | | $SO_4$ | |
| | | WY 1962-4/87 | 5/87-WY 1998 | WY 1962-4/87 | 5/87-WY 1998 |
| Natural | | 1.140 | 1.168 | 1.000 | 1.130 |
| Modified | 8 Only | 0.776 | 0.800 | 0.869 | 1.000 |
| | 8 & 10 | 0.669 | 0.714 | 0.742 | 0.891 |
| | 7 & 8 | 0.378 | 0.416 | 0.659 | 0.697 |
| | 7, 8 & 10 | 0.271 | 0.330 | 0.532 | 0.681 |

The above factors reflect the effects of pumping from the Low Flow Dams plus:

1. A 5% reduction in Cl loads due to man-made cleanup (see Section IV).
2. An adjustment of Cl loads before and after May 1987 (Section VII).
3. A reduction of 64.5 tons per day was made prior to May 1987 (+ 14%).
4. And an increase of 89.5 tons per day was made after May 1987 (-15%).

**WICHITA FALLS GAGE**

Modified concentrations at the Wichita Falls gage were computed similar to the Mabelle gage. Table C-5 shows the factors used.

**TABLE C-5**

**FACTORS USED TO MODIFY CONCENTRATIONS AT THE WICHITA FALLS GAGE**

| Type of Flow | Plan | Factors Used | | | | | |
|---|---|---|---|---|---|---|---|
| | | Cl | | $SO_4$ | | TDS | |
| | | WY 1962 -4/87 | 5/87- WY 1998 | WY 1962 -4/87 | 5/87 – WY 1998 | WY 1962 -4/87 | 5/87 – WY 1998 |
| Natural | | 1.116 | 1.185 | 1.000 | 1.197 | 1.116 | 1.176 |
| Modified | 8 Only | 0.814 | 0.770 | 0.841 | 1.000 | 0.838 | 0.850 |
| | 8 & 10 | 0.726 | 0.673 | 0.686 | 0.835 | 0.739 | 0.736 |
| | 7 & 8 | 0.487 | 0.337 | 0.586 | 0.683 | 0.553 | 0.461 |
| | 7, 8 & 10 | 0.399 | 0.240 | 0.432 | 0.518 | 0.454 | 0.348 |

The factors used reflect the effects of pumping from the Low Flow Dams plus:

1. A 5% reduction in Cl loads due to man-made cleanup (see Section IV) as computed at Mabelle (23 T/D for WY 1962 - Apr 1987; 29 T/D after May 1987).

2. An adjustment of Cl loads before and after May 1987 (See Section VII). A reduction of 64.5 T/D was made prior to May 1987 and an increase of 89.5 T/D was made after May 1987.

## TERRAL GAGE

Modified concentrations were computed similar to the Wichita Falls gage. Table C-6 shows the factors used.

**TABLE C-6**

**FACTORS USED TO MODIFY CONCENTRATIONS AT THE TERRAL GAGE**

| Type of Flow | Plan | Factors Used | | | | | |
|---|---|---|---|---|---|---|---|
| | | Cl | | $SO_4$ | | TDS | |
| | | WY 1962-4/87 | 5/87-WY 1998 | WY 1962 -4/87 | 5/87-WY 1998 | WY 1962 -4/87 | 5/87–WY 1998 |
| Natural | | 1.020 | 1.018 | 1.000 | 1.015 | 1.012 | 1.017 |
| Modified | 8 Only | 0.967 | 0.978 | 0.979 | 1.000 | 0.973 | 0.988 |
| | 8 & 10 | 0.951 | 0.968 | 0.959 | 0.987 | 0.956 | 0.977 |
| | 7 & 8 | 0.909 | 0.933 | 0.945 | 0.974 | 0.925 | 0.951 |
| | 7, 8 & 10 | 0.893 | 0.923 | 0.925 | 0.961 | 0.908 | 0.941 |

## GAINESVILLE GAGE

Modified concentrations were computed similar to the Wichita Falls gage. Table C-7 shows the factors used

**TABLE C-7**

**FACTORS USED TO MODIFY CONCENTRATIONS AT THE GAINESVILLE GAGE**

| Type of Flow | Plan | Factors Used | | | | | |
|---|---|---|---|---|---|---|---|
| | | Cl | | $SO_4$ | | TDS | |
| | | WY 1962 -4/87 | 5/87-WY 1998 | WY 1962 -4/87 | 5/87-WY 1998 | WY 1962 -4/87 | 5/87-WY 1998 |
| Natural | | 1.018 | 1.015 | 1.000 | 1.010 | 1.011 | 1.013 |
| Modified | 8 Only | 0.972 | 0.982 | 0.980 | 1.000 | 0.976 | 0.990 |
| | 8 & 10 | 0.958 | 0.974 | 0.961 | 0.991 | 0.961 | 0.982 |
| | 7 & 8 | 0.921 | 0.947 | 0.949 | 0.983 | 0.933 | 0.964 |
| | 7, 8 & 10 | 0.907 | 0.940 | 0.929 | 0.974 | 0.919 | 0.956 |

## DENISON GAGE

Modified concentrations were computed similar to the Wichita Falls gage. Table C-8 shows the factors used.

**TABLE C-8**

**FACTORS USED TO MODIFY CONCENTRATIONS AT THE DENISON GAGE**

| Type of Flow | Plan | Factors Used | | | | | |
|---|---|---|---|---|---|---|---|
| | | Cl | | $SO_4$ | | TDS | |
| | | WY 1962 -4/87 | 5/87- WY 1998 | WY 1962 -4/87 | 5/87- WY 1998 | WY 1962 -4/87 | 5/87- WY1998 |
| Natural | | 1.020 | 1.018 | 1.000 | 1.015 | 1.012 | 1.017 |
| Modified | 8 Only | 0.967 | 0.978 | 0.979 | 1.000 | 0.973 | 0.988 |
| | 8 & 10 | 0.951 | 0.968 | 0.959 | 0.987 | 0.956 | 0.977 |
| | 7 & 8 | 0.909 | 0.933 | 0.945 | 0.974 | 0.925 | 0.951 |
| | 7, 8 & 10 | 0.893 | 0.923 | 0.925 | 0.961 | 0.908 | 0.941 |

# APPENDIX D

# LAKE KEMP SEDIMENTATION ANALYSIS

## LAKE KEMP SEDIMENTATION ANALYSIS

Lake Kemp was originally constructed in 1924 by the City of Wichita Falls and Wichita County Water Improvement District. Lake Kemp was redesigned, with COE involvement, in the 1960's. The goal of the redesign and reconstruction was to add additional flood control storage. Loss of storage to sedimentation was taken into account during the design effort. Lake Kemp was designed with additional flood storage so the conservation pool could be raised at regular intervals throughout the life of the project to regain storage lost to sedimentation. Pool rises were planned for 2008, 2028, 2048, and 2068 with the maximum conservation pool at elevation 1150.

The original design projected sediment loss equally throughout the conservation and flood pool. Subsequent sedimentation surveys indicate that the majority of sediment has been deposited in the conservation pool with limited loss of storage in the flood pool. Recent partial sedimentation surveys, using improved technology and methods, indicate that storage loss at Lake Kemp is not as dramatic as originally estimated.

Using recent partial sedimentation data and projected storage loss estimates, Lake Kemp capacity was estimated for 50 and 100 years into project life starting in 2005. An annual storage loss of 1451 acre feet was used. Conservation storage at 50 years at elevation 1148 was estimated to be 261,000. Conservation storage at elevation 1150 at 100 years was estimated to be 223,000 acre feet. Current conservation storage is estimated to be 263,000 acre feet.

A computer routing program was developed to simulate existing conditions and future conditions after project completion. The computer routing program was designed to route monthly historical inflows, evaporation, and precipitation through Lake Kemp. The period of record used was WY 1949 to CY 2000. Monthly releases were based on the existing and projected water usage listed in Table 1. The program assumed that the top of conservation pool was elevation 1148 at 50 years and elevation 1150 at 100 years and all storage one foot above the top of the conservation pool was floodwater and immediately released. The program also assumed brush control implementation in 50% of the basin above Lake Kemp and below the collection areas.

**Table 1**
**Existing and Projected Water Usage in Lake Kemp**

| | Existing Water Usage Acre Feet/Year | Projected Water Usage Acre Feet/Year |
|---|---|---|
| **Irrigation** | **80,000** | **120,000** |
| **Municipal** | **0** | **11,222** |
| **Industrial** | **10,000** | **20,000** |
| **Recreation** | **5,850** | **5,850** |
| **TPWD Hatchery** | **2,200** | **2,200** |

The Wichita County Water Improvement District was required by Texas Senate Bill 1 to develop and implement a drought contingency plan for Lake Kemp in CY2000. The drought contingency plan created action levels that required reductions in water usage at specific elevations. The drought contingency requirements are listed in Table 2. The drought contingency water use requirements were installed in the routing program. Drought contingency action levels for 50 and 100 years into project life were chosen based on storage volumes similar to original storage volumes set by the CY2000 Drought Contingency Plan. The drought contingency action levels for 50 and 100 years are listed in Table 3.

**Table 2**
**Drought Contingency Water Usage Assumptions**

| | Level I | Level II | Level III | Level IV |
|---|---|---|---|---|
| **Irrigation** | **100%** | **50%** | **25%** | **0%** |
| **Municipal** | **100%** | **100%** | **100%** | **100%** |
| **Industrial** | **100%** | **100%** | **100%** | **100%** |
| **Recreation** | **100%** | **0%** | **0%** | **0%** |
| **TPWD Hatchery** | **100%** | **0%** | **0%** | **0%** |

**Table 3**
**Drought Contingency Action Levels**

| | Conservation Pool, Top | Level I | Level II | Level III | Level IV |
|---|---|---|---|---|---|
| **50 Years** | 1148 | 1148-1130 | 1130-1122 | 1122-1117 | 1117 & Below |
| **100Years** | 1150 | 1150-1133 | 1133-1125 | 1125-1120 | 1120 & Below |

The routing program output was sorted and durations were developed for critical elevations. Duration data for existing, existing with brush control, selected plan with brush control, and selected plan with brush control at 50 and 100 years into project life are listed in Table 4.

The routing program output indicates that sufficient storage will be available at 100 years into project life to sustain the projected irrigation water use. Only slight changes in the percent of time drought contingency action levels will be equaled or exceeded are seen at 50 and 100 years. With the top of conservation pool at it current level, elevation 1123 will be equaled or exceeded 85.2 to 88.3% of the time with the selected plan with 50% brush control. The corresponding drought contingency Level II elevation at 100 years, elevation 1133, will be equaled or exceeded 85.7 to 88.0% of the time.

## Table 4
## Lake Kemp Elevation Duration Data

| Existing Drought Action Level Elevations | Percent of Time Equaled or Exceeded | | | |
|---|---|---|---|---|
| | **1109** | **1114** | **1123*** | **1144**** |
| **Existing Conditions** | 100% | 100% | 100% | 29.3% |
| **Existing Conditions w/ 50% Brush Control -27.6%** | 100% | 100% | 100% | 31.4% |
| **Existing Conditions w/ 50% Brush Control – 38.9%** | 100% | 100% | 100% | 33.3% |
| **Selected Plan w/50% Basin Brush Control 27.6%** | 100% | 99.3% | 85.2% | 13.2% |
| **Selected Plan w/50% Basin Brush Control 38.9%** | 100% | 99.7% | 88.3% | 14.3% |
| | **Percent of Time Equaled or Exceeded** | | | |
| **50 Drought Year Action Level Elevations** | **1117** | **1122** | **1130*** | **1148**** |
| **Selected Plan w/50% Basin Brush Control 27.6%** | 100% | 98.9% | 85.4% | 13.2% |
| **Selected Plan w/50% Basin Brush Control 38.9%** | 100% | 99.7% | 88.0% | 14.5% |
| | **Percent of Time Equaled or Exceeded** | | | |
| **100 Drought Year Action Level Elevations** | **1120** | **1125** | **1133*** | **1150**** |
| **Selected Plan w/50% Basin Brush Control 27.6%** | 100% | 98.2% | 85.7% | 14.5% |
| **Selected Plan w/50% Basin Brush Control 38.9%** | 100% | 98.4% | 88.0% | 14.6% |

*Level II, 50% irrigation, 0% TPWD
**Top of conservation pool